GEORGIA INSTITUTE OF TECHNOLOGY OFFICE OF CONTRACT ADMINISTRATION

PROJECT ADMINISTRATION DATA SHEET

[X] ORIGINAL [ ] REVISION NO. ______

Project No. E-16-644 (Continuation of E-16-684) GTRI/~~GIT~~ DATE 7/16/84

Project Director: Dr. A. L. Ducoffe/Dr. R. B. Gray School/~~Lab~~ Aerospace Engr.

Sponsor: US Army Research Office
Research Triangle Park, NC 27709

Type Agreement: Mod. P00003 to SFRC DAAG29-82-K-0094

Award Period: From 7/1/84 To 6/30/86 (Performance) 8/30/86 (Reports)

Sponsor Amount:

	This Change	Total to Date
Estimated:	$ ---	$ 4,300,000 (Total Contract)
Funded:	$ 1,200,000	$ 1,200,000 (Total Contract $300,

Cost Sharing Amount: $ 247,309 Cost Sharing No: E-16-320 (Cont. of E-16-314

Title: A Center of Excellence for Rotary Wing Aircraft Technology

ADMINISTRATIVE DATA

OCA Contact William F. Brown X4820

1) Sponsor Technical Contact:

Dr. Robert E. Singleton
US Army Research Office
P. O. Box 12211
Research Triangle Park, NC 27709

2) Sponsor Admin/Contractual Matters:

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(Same address as on left) 919-549-0641
For all matters except as covered by
ONR RR.
Mr. T. A. Bryant, ONR RR
(Property, patent, invoice & closing mat
Campus

Defense Priority Rating: N/A

Military Security Classification: Unclassified

(or) Company/Industrial Proprietary: N/A

RESTRICTIONS

See Attached SFRC Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval — Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

Equipment: Title vests with GIT (Prior sponsor approval required for purchase of and title to equipment).

COMMENTS:

Mod. P00003 adds 3rd year funding through 6/30/85. New project number assigned for GIT accounting purposes.

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Accounting	Research Communications (2)	Other I. Newton

GEORGIA INSTITUTE OF TECHNOLOGY　　　　OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION/CLOSEOUT SHEET

Date February 3, 1986

Project No. E-16-644 (Closeout of Project No. Only)　　School/~~Lab~~ AE

Includes Subproject No.(s) N/A

Project Director(s) Drs. A.L. Ducoffe/R.B. Gray　　GTRC / ~~GIT~~

Sponsor U.S. Army Research Office-Research Triangle Park, NC 27709

Title A Center of Excellence for Rotary Wing Aircraft Technology

Effective Completion Date: 6/30/86 (Performance) 8/30/86 (Reports)

Grant/Contract Closeout Actions Remaining:

- [X] None
- [ ] Final Invoice or Final Fiscal Report
- [ ] Closing Documents
- [ ] Final Report of Inventions
- [ ] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
- [ ] Other ______

Continues Project No. E-16-684　　Continued by Project No. E-16-687

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FORM OCA 69.285

E-16-684

PROGRESS REPORT

(TWENTY COPIES REQUIRED)

1. ARO PROPOSAL NUMBER: 19364-E

2. PERIOD COVERED BY REPORT: 1 July 1982 to 31 December 1982

3. TITLE OF PROPOSAL: A CENTER OF EXCELLENCE IN ROTARY WING AIRCRAFT TECHNOLOGY

4. CONTRACT OR GRANT NUMBER: DAAG29-82-K-0094

5. NAME OF INSTITUTION: SCHOOL OF AEROSPACE ENGINEERING GEORGIA INSTITUTE OF TECHNOLOGY

6. AUTHOR(S) OF REPORT: R. B. Gray (Co-Principal Investigator), J. I. Craig, S. V. Hanagud, J. E. Hubbartt, S. G. Lekoudis, H. M. McMahon, G. A. Pierce, & J. C. Wu

7. LIST OF MANUSCRIPTS SUBMITTED OR PUBLISHED UNDER ARO SPONSORSHIP DURING THIS PERIOD, INCLUDING JOURNAL REFERENCES:

Method of Multiple Scales and Identification of Nonlinear Structural Dynamic Systems, S. V. Hanagud, M. Meyyappa, and J. I. Craig, 24th Structures, Structural Dynamics and Materials Conf., May 1983.

A Comparison of Finite Difference Schemes for Second Piola-Kirchhoff Formulation, S. V. Hanagud and N. S. Abhyankar, International Symposium on Numerical Methods, Paris, France, March 1983.

8. SCIENTIFIC PERSONNEL SUPPORTED BY THIS PROJECT AND DEGREES AWARDED DURING THIS REPORTING PERIOD:

Faculty: J. I. Craig, A.L. Ducoffe, R.B. Gray, S.V. Hanagud, J.J.Harper, J. E. Hubbartt, H.M. McMahon, G.A. Pierce, and J. C. Wu

Research Engineers: S. Kleinhaus and N. Sankar

Research Associates: J. Caudell, H. Meyer, and D. Ransom

Fellows: Thomas M. Boyd, Cynthia P. Boyette, Kathryn D. Dunlop, Thomas C. Parham, Gregory D. Power, and Thomas L. Thompson

Graduate Research Assistants: V.R.P. Jonnalagadda, J. W. Rogers, P. Siram, and T. C. Wey

Personnel Involved But Not Supported: Capt. M.R. Clifford and Capt. W.S. McArthur - U.S. Army

Degrees Awarded: Capt. M.R. Clifford, Master of Science, Dec. 1982

Dr. Robin Gray 19364-E
Dr. A. L. Ducoffe
Georgia Institute of Technology
School of Aerospace Engineering
Atlanta, GA 30332

RESEARCH TASKS

I. Aerodynamics

Task 1. Experimental Studies for Tip Vortex Core Modelling
R. B. Gray

The objective for this investigation is to obtain data for guiding the development of a tip vortex core model to use in free wake analyses for predicting helicopter blade loadings. A laser doppler velocimeter data acquisition system is being acquired for this purpose. The status of this system is described in the Facilities/Equipment Section of this report. In accordance with the original proposal and approved budget, the system will not be fully operational until the second year of the contract.

The tests will be conducted in the Nine-Foot Static Thrust Facility and the measurements will be made in the wake of an existing single-bladed model rotor. The single-bladed model rotor offers a particular advantage in that the interaction of the discrete vortex systems in the wakes of multi-bladed rotors is avoided.

Task 2. Modification of Blade Tip Loading to Improve Hovering Figure of Merit
R. B. Gray

Measured surface pressure distributions near the tip of a hovering model rotor blade indicate that the dominant feature is the low pressure region associated with the roll-up and rearward sweep of the tip vortex over the upper surface of the trailing 50% of the blade chord. The resulting rearward shift in center of pressure leads to an approximately doubling of the section in-plane force coefficient and hence significantly contributes to the rotor power required. The objective of this task is to investigate the feasibility of modifying this pressure distribution to improve the hovering figure of merit.

Based on some previous test results, the tip configuration has three small winglets mounted on the square, flat tip surface near the leading edge of the blade. These winglets have a chord length of 5% and a maximum span of 20% of the blade tip chord. The winglet span is varied by changing sets of winglets which have been constructed. Each winglet incidence angle relative to the blade tip chord can be manually set. A new blade tip with attachment points for the winglets has been constructed and installed on the existing blade. The test program has been planned and initiated. Although a considerable range of span and incidence angle variations for the three-winglet configuration has been tested, the data are, at present, not sufficiently complete to indicate trends.

Task 3. A Procedure for Computing Rotor-Blade/Tip-Vortex Interactions
R. B. Gray and S. G. Lekoudis

An iterative lifting surface method has been developed for computing the surface pressure distribution in hover on a thick rotor blade with a half-body of revolution tip. A comparison of the results in the tip region with experimental data shows that the method yields good agreement on the lower surface and on the upper surface near the leading edge where the tip relief effect predominates. However, the method does not satisfactorily predict the pressure distribution associated with the rearward sweep of the tip vortex over the upper surface aft of the 50% chord station. Therefore, the objective of this investigation is to study simplified flow models which may lead to better results in this region.

The basic viewpoint underlying the development of this method was to assess the viability of an inviscid, incompressible flow model with the implied classical theorems while employing empiricisms which appear to be reasonably well accepted. For example, it is required: that the computed and measured thrust be in close agreement; that the maximum bound vortex and the fully developed tip vortex strength be in close agreement; that the tip vortex geometry be prescribed and correspond with that measured for a rotor having the same thrust coefficient and number of blades; and, a questionable but necessary empiricism, that the effect of Reynolds number can approximately be accounted for by adjusting the blade pitch angle. The one major inconsistency from the classical viewpoint is that no attempt is made to model or require vortex filament continuity from the blade surface to the tip vortex. The major unknowns are the geometry of what might be called the central curve and the local strength of the tip vortex as it develops and sweeps rearward over the blade.

During this reporting period, it was assumed that the prescribed tip vortex geometry began just off the blade trailing edge and numerical experimentation was employed to extend the central curve of the tip vortex forward over the blade to about the quarter-chord point. A trial and error process was used first with both a linear and a quadratic variation in tip vortex strength. The result was reasonably good agreement with the measured pressure distribution. More recently, a procedure was developed to compute this central curve location. The results were not available at the end of the reporting period.

The long term objectives of this task include the capability of obtaining solutions of the flow around a blade tip without empirical input. The following paragraphs describe some efforts expended towards achieving this objective.

The flow around the blade tip is characterized by a strong tip vortex and the wake of the blade. Solutions of the three-dimensional unsteady Navier-Stokes equations for turbulent flows (time-averaged) could, in principle, accurately model this flowfield. However extensive computer resources are needed to obtain this goal. As an intermediate step, solutions of the Euler equations could also be used for the same purpose. These solutions can capture the separated flow vorticity (Ref. 1) and do not require the extensive grid-refinements close to the body that Navier-Stokes solvers do. Moreover they are independent of the speed regime and, being field solutions, they do not have the numerical difficulties that vortex lattice grids around complicated geometries do. However, they also require extensive computer resources.

Dr. N. L. Sankar has written a three-dimensional Euler Solver and he is currently executing a two-dimensional version of the above code. The method used works as follows. The conservation form of the Euler equations is used with a linearization in time. The resulting implicit scheme is solved by an Alternating Direction Implicit procedure (Ref. 2). The boundary conditions are applied as follows. Freestream conditions are applied at the outer boundary. At the downstream boundary the pressure is assumed known and the other quantities are extrapolated from the last interior grid location. At the blade surface the normal velocity is set equal to zero and the other solution variables are extrapolated from the last interior point.

In order to examine viscous effects inboard of the last few percent of the blade examined in Ref. 3, the following calculations were made. The airfoil section of the blade was assumed at the angle of attack given by the geometric angle of attack and the effect of the tip vortex. Then the two-dimensional flowfield was computed using GRUMFOIL (Ref. 4). The obtained pressure distributions were in good agreement with the measurements. This indicates that if the proper effective angle of attack is used in hover, the flowfield in the inboard 95% of the blade span can be accurately predicted using two-dimensional viscous/inviscid coupling procedures. This statement applies for rotors of the type tested in Ref. 3 only.

References

1. "Slender Wings with Leading-Edge Vortex Separation - A Challenge for Panel-Methods and Euler-Codes" by Hitzel S.M. and Schmidt, W., AIAA Paper 83-0562.

2. "Implicit Finite-Difference Simulations of Three-Dimensional Compressible Flow" by Pulliam, T.H. and Steger, J.L., AIAA Journal, Vol. 18, No. 2, pp. 159-167, 1980.

3. "Surface Pressure Measurements at Two Tips of a Model Helicopter Rotor in Hover," by Gray, R.B., McMahon H.M., Shenoy, K.R. and Hammer, M.L., NASA CR-3281, May 1980.

4. "Computation of Viscous/Inviscid Interactions", AGARD CP No. 291, 1981, Paper No. 10 by R. Melnik.

Task 4. Studies in Unsteady Rotor Aerodynamics
J. C. Wu and N. L. Sankar

As part of the research, a versatile computer program has been written for computing viscous and inviscid flows past arbitrary airfoils undergoing arbitrary motion. This program uses a body-fitted moving curvilinear coordinate system to solve the governing equations. Any combination of pitching and plunging motions of the airfoil may be treated. The airfoil section may be completely arbitrary. Compressibility effects may be considered, including situations where embedded shocks are periodically formed on the upper surface.

This program uses an Alternating-Direction - Implicit time marching procedure for extended numerical stability. The primitve variables have been chosen as the unknowns in the present approach instead of the vorticity-stream function approach primarily in order to remove boundary calculations required by the vorticity-stream function approach.

The present version uses surface pressure integration to compute the loads. In the future, the aerodynamic loads will be computed using the generalized aerodynamic forces theory developed by the principal investigator. The latter approach is preferred because of the physical insight that it offers into the flow features.

In anticipation of the 3-D flow calculations to be performed in the later part of the present work, work has begun on a 3-D viscous and inviscid flow solver.

Task 5. Studies of the Airframe Flow Field in Forward Flight
J. E. Hubbartt, H. M. McMahon, and S. S. Kleinhaus

During this period much effort has been devoted to upgrading the 9-foot wind tunnel facility as well as to establishing the specifications and then procuring the LDV. That work is discussed in separate sections of this progress report. Nevertheless, considerable progress has been made in preparation for this research program.

Preliminary design of the rotor drive and support system has been completed and final structural analysis is in progress. This rotor system is to be supported in a cradle located symmetrically above the wind tunnel and attached to existing support beams which are separated from the wind tunnel structure. Translation and rotation of the rotor system within the fixed cradle will permit changes in location and direction of the thrust vector. The lift will be upward and the fuselage will be mounted separately to the external wind tunnel balance. The rotor drive system consists of a variable-speed, 3 HP DC motor with controller and speed indicator which are on order. Preliminary design and analysis of the rotor blade has been completed. The two-bladed rotor will be 3' in diameter and use an NACA 0015 airfoil section with 3.4" chord. The blades will be made of steel and wood so that the CG is slightly ahead of the quarter chord. The relatively high solidity has been selected so as to permit high induced velocities with relatively low tip speeds (for safety reasons) and with the highest blade Reynolds numbers. The design selected gives a maximum thrust and thrust coefficient in hover of about 35 #F and 0.015, respectively. Design of the hub section is in progress. It is planned to use a simple seesaw attachment with fixed blade pitch and no lead/lag hinge. Because of the simple hub arrangement, pitch changes will be made by using interchangeable hub sections.

In addition, during this reporting period some available techniques for predicting the flow over the fuselage have been studied and simple calculations have been made to gain experience and insight. These studies will be continued with the dual objectives of having a workable technique programmed for analysis when experiments become available and of having a basis for incorporating any desirable modifications.

II. Structures

Task I. Structural Dynamic System Identification
S. V. Hanagud and J. I. Craig

Research efforts have been directed towards improving the state-of-the-art techniques for structural dynamic modelling of the airframe of rotory wing vehicles. Current techniques do not yield results to a level of accuracy that is effective in design processes. In particular, computed mode shapes and forced responses are either unacceptable or marginal in regions of practical interest. Some of the significant reasons for the discrepancy can be attributed to the existence of nonproportional damping, inaccurate modelling techniques and the presence of nonlinear effects.

In order to incorporate any nonlinear effects that might be present or to rule out the existence of nonlinear terms in the system, a perturbation identification procedure has been developed. The perturbation identification procedure is applicable to systems with small nonlinearities. As a first step, the procedure has been developed for a system with single degree of freedom and cubic nonlinearity in the stiffness terms. The input to the system is in the form of an impulse force that can be generated by a calibrated hammer. The developed perturbation identification procedure has been compared with the existing procedure. It has been found that the developed procedure is superior to the existing procedures for noisy data and small nonlinearities.

The perturbation identification procedure is being generalized to consider other nonlinear effects and forcing functions.

Research efforts are also being directed towards developing techniques for designing structural dynamic scale models of helicopter airframes. The models will be physical lumped mass systems. A generic airframe has been selected for this study. Initially, the technique is being tested for simple structural dynamic systems other than the complete air frame. The purpose of these tests is to validate the technique.

At present, a physical lumped mass model of an airframe is being fabricated. This model is based on the information provided by Dr. Calapodas of A.T.L. at Fort Eustis, Virginia. Laboratory tests of the model are being planned. Major attention will be directed at simulating the nonlinearities treated in the analytical work and at dealing with discrete effects involving mass and damping action associated with large lumped masses within the structure. Supporting work involves acquisition of a small amount of vibration response instrumentation for the immediate work and preliminary planning for further major additions to the laboratory facilities during the second grant year.

Efforts are also underway to acquire several structural models and actual subassemblies, such as a helicopter tail boom, for laboratory tests.

Task 2. Crashworthy Characteristics of Composite Airframe Structures
S. V. Hanagud

Primary research efforts have been directed toward the study of the post-buckling behavior of composite sandwich structures with crush zones. Two specific plate specimens have been fabricated. A crush zone is made of a locking type of material consisting of a memory foam. A second crush zone consists of a honeycomb type of material. The second crush zone was selected primarily to study and develop techniques for attaching the crush zones to composite flat plates. Two other structures with a keel web crush zone and a corrugated web crush zone have been planned. Composite face plates have also been produced in the laboratory from woven graphite satin cloth and fiberite resin.

As a first step, static post-buckling tests have been planned. A compression loading frame has been designed and fabricated. At present, some changes are being incorporated to yield the correct boundary conditions. The post-buckling deflections will be measured by using a white light speckle technique. The current technique that is used by other investigators to measure the post-buckling deformations is the Moire technique which pose difficulties for quantitative evaluation in this application. The instrumentation system for white light speckle technique has been developed and validated by using a "control experiment" of the bending of a circular plate. The next step is to test the buckling behavior of face plates and post-buckling behavior of the sandwich plates.

This phase of the project is concerned with estimating the transient dynamic response of the composite face plates and crush zones where the structure is subjected to dynamic crash loads. Second order accurate finite difference methods and difference generated element techniques are being developed for this study. At present, different techniques are being compared for accuracy and efficiency. This is being done by considering standard elastic-plastic problems. A paper on this subject has been prepared and submitted for publication. The benefits of state space methods are also being studied. In the past, the state space methods, however, have not been studied extensively. These methods have the potential of providing computationally efficient techniques for crashworthy analysis. Therefore, initially linear problems are being studied by using state space methods.

The problem of optimum fiber distribution for the dual role of crashworthy and airworthy behavior of structures is of concern in this phase of the project. A simple problem of optimum fiber distribution in bending and torsion has been formulated. The foundations for this work is the basic theory of Prager-Shield and the formulations by Strang. Numerical optimization procedures are being developed for the formulation. A paper is being prepared in this subject.

III. Aeroelasticity

Task 1. Helicopter Vibration Suppression Techniques
G. A. Pierce

The objective of this program is to develop an analysis of rotor systems for the determination of vibratory loads and the design of vibration suppression systems. To achieve this objective, special emphasis will be placed on each of the following aspects of the problem.

1) Structural dynamics of the blades
2) Hub dynamics and impedance of the rotor/airframe interface
3) Dynamics of blade-mounted and hub-mounted absorbers
4) Unsteady blade aerodynamics due to elastic deformations
5) Unsteady blade aerodynamics due to cyclic pitch control in forward flight
6) Unsteady blade aerodynamics due to higher harmonic pitch control

The structural dynamic representation of a typical blade has been formulated and programmed for solution using the transfer matrix technique. This simulation includes flap, lead-lag and torsional degrees of freedom with the effects of mass-elastic axes offset, prepitch, pretwist and precone for a nonuniform blade.

Boundary conditions at the blade root are currently being formulated in a general fashion to be compatible with articulated, hingeless, bearingless, etc., configurations. This general treatment includes both a finite off-set from the rotational axis and rigid-body hub dynamics. The hub dynamics will be determined in response to the combined root reactions of the blades and the impedance of the rotor/airframe interface.

Work has been initiated on a comprehensive formulation of the unsteady aerodynamic loading on the blades due to elastic deformations. This development is a two-dimensional treatment whose results will be applied in a strip theory manner. Since these loads are simply perturbations induced by the structural dynamic response, three-dimensional effects should have a minimal influence. All three types of motion (lead-lag, flap and torsion) are being considered simultaneously in the development. The implication of including the lead-lag motion is to impose an effective fluctuation in the free-stream speed and thus generate integral harmonics in the resulting air loads.

FACILITIES/EQUIPMENT

I. Laser Doppler Velocimeter Data Acquisition System
R. B. Gray, J. E. Hubbartt, H. M. McMahon, G. A. Pierce,
and N. Komerath

Final specifications for the LDV system were established after detailed discussions with all vendors involved and after detailed analysis of the technical requirements and physical constraints of the different facilities and proposed applications. On the basis of competitive bids, a Spectra Physics 4-watt Argon laser, together with TSI optics, electronics, and 3-axis optical traverse system, were selected. The complete system features capabilities for simultaneous, non-intrusive measurement of two components of velocity with a spatial resolution of 0.1 mm. Both magnitude and direction of velocity can be measured over a range from .0007 to 1400 mps. The measuring location can be positioned anywhere within a 600 x 600 x 900 mm parallelepiped, under computer control. An HP 1000 A-700 computer system will be used for actuator control, data acquisition, and processing. The complete system is transportable as a unit between facilities.

Cooling and power lines required for the laser have been installed at the 9-foot rotor facility. The laser has been received, installed, and checked out. Optics and electronics modules for measuring one component of velocity have been received, and are being installed. The computer system is on hand, and will be operational in the near future. Work has begun on writing data acquisition and processing software, and on developing an air-blast atomizer seeder to produce small water particles.

The traverse system is scheduled for delivery in March. The optical and electronic modules required to complete the two-component LDV will be purchased next year.

II. Nine-Foot Static Thrust Facility
R. B. Gray and S. S. Kleinhaus

The facility was designed to provide a laboratory-controlled environment for testing model helicopter rotors up to 4 1/2 feet in diameter in hovering flight. This facility is to be updated over a period of several years. The modifications have been scheduled to permit some interim testing.

The LDV system will have its first use in this facility and plans for its installation are complete. The power and cooling-water lines have been installed. The laser has been received and has been checked out.

The mercury slipring assembly is scheduled to be reconditioned during the next reporting period. A new balance system and data acquisition system is planned for later years.

III. Structural Dynamic System Identification Facility
S. V. Hanagud and J. I. Craig

No significant facility developments are planned for the first year.

IV. Transient Dynamic Stress Analysis Facility
S. V. Hanagud

A preliminary design outline for the design of the dynamic test facility has been completed. At present, the instrumentation systems are being evaluated. A specific dynamic test facility that has been used in the Israel Institute of Technology is being evaluated. The purpose of the evaluation is to incorporate some of the instrumentation system in our design.

V. Nine-Foot Wind Tunnel Facility
J. E. Hubbartt, H. M. McMahon, J. J. Harper, S. S. Kleinhaus, and N. Komerath

Upgrading of this existing facility, which is to be used for forward flight experiments, was started during this period. The goals originally proposed were to incorporate a modern computer-based data acquisition system and a minimum of instrumentation necessary for mean and fluctuating pressure and velocity measurements. However, two other developments of great importance to this facility and to future research have occurred during this period. First, it has been determined that Georgia Tech will provide additional funds to rework the wind tunnel control panel, improve the lighting, isolate the control room, and provide for environmental control. Besides providing a vast improvement in the control room working area, these modifications will ensure a clean and controlled environment essential for the new instrumentation and computer. Second, the Georgia Division of Lockheed Aircraft Corporation has agreed to provide $100,000 of additional funds over a two-year period for improving the wind tunnel and instrumentation. Plans are underway now to use a portion of those funds to install a flat floor and ceiling which will reduce the overall height of the test section to 7 feet but with improved flow conditions and more convenient use of the wind tunnel balance. Additional work to be completed in this first phase is the installation of a honeycomb immediately after the turning vanes upstream of the inlet contraction, calibration of the test section flow and the reconditioning of the drag force system in the balance. In the second year, automatic plotters and more pressure measuring instrumentation will be added.

During this reporting period all of the work on this facility has been devoted to the extensive planning necessary for the upgrading of the facility discussed above. At the present time, specifications for most of the modifications such as the control room, instrumentation, and the test section flat floor and ceiling have been drawn up. Detailed design will now begin. Also, most of the planning required for the use of the LDV (discussed elsewhere in this progress report) with this facility has been completed. This has involved questions related to the location and environmental control for the LDV, the support of the system, and transporting the system to and from the facility. The planning has been complicated by the constraints that the LDV must be used with several facilities, the entire LDV system is heavy and bulky, and the wind tunnel test section is elevated and partially obstructed by the balance linkages.

VI. Sixteen-Foot Rotor-Test Facility Development
G. A. Pierce, R. B. Gray and S. S. Kleinhaus

This test facility will consist of a horizontal cylindrical shroud of sixteen-foot diameter which is approximately, twenty feet long. The shroud will be constructed of honeycomb to eliminate the vorticity of the recirculating flow. The downstream end will contain a honeycomb partition with a wake inductor concentric with the longitudinal axis to permit the free passage of the rotor wakes. The return flow will be within a large room surrounding the shroud. A horizontal drive shaft will be driven by an external variable-speed motor-controller system with a maximum speed capability of 2000 rpm. A fifty-two-channel slip-ring assembly will be installed in the rotating system for transmission of data signals. The initial rotor configuration will incorporate an instrumented hub which can accommodate either one, two or four-bladed systems with manual pitch control.

Immediately adjacent to the facility will be a control room for remote operation of the drive mechanism and data conditioning and analysis. In addition to an operator's control panel, this room will contain instrumentation power supplies, amplifiers, recorders, and other miscellaneous signal conditioning equipment. A major component of this equipment will be a computer-based data acquisition system.

The detailed design and analysis of the shroud and support for the drive system and shaft is nearly complete. The variable-speed motor-controller system has been selected and a purchase order is being processed. This drive system will consist of an eddy current clutch to control the power output of a conventional AC motor. The electronic package required to generate the variable speed feature is small, requires little maintenance, and passes only 2% of the power so it can be remotely located. This 30 HP system will have a maximum speed of 2000 RPM which will be stabilized to an accuracy of 0.1%.

NEW COURSE DEVELOPMENT

The development of the following courses has begun. The development of the remaining proposed new courses has been scheduled for a later reporting period.

I. System Identification
S. V. Hanagud and J. I. Craig

An exhaustive literature survey in the field of system identification is in progress. Several specific identification techniques have been selected for inclusion in the course. For these techniques, numerical examples are being developed. The specific techniques selected include Ibrahim's time domain method, direct method and Baruch's methods.

II. Finite Deformation of Aircraft Structures
S. V. Hanagud

A course outline has been prepared. A computer program has been written to study the benefits and disadvantages of different formulations. At present, introductory material for the course is being arranged.

III. Computational Aerodynamics
S. G. Lekoudis

This is an introductory course in computational aerodynamics. The course outline has been prepared and the lecture notes are essentially complete.

IV. Numerical Fluid Dynamics III
J. C. Wu

Efforts have been devoted to the development of the above titled new course. Plans are being made to offer this course in the Fall quarter of 1983. This new course is designed to acquaint the students with the state-of-art engineering applications of computational aerodynamics. Studies of rotors and wakes with applications in rotary wing aircraft analyses will be a part of the course.

UPDATED COURSES

I Advanced Compressible Flow Theory II
S. G. Lekoudis

This course is to be modified to include material on transonic flow on helicopter blades in forward flight. This has been scheduled for the next reporting period.

II. Advanced Potential Flow I & II
G. A. Pierce

The modification of these courses has been completed by adding material on the phenomena that is unique to helicopter rotor blades. The added material includes topics on blade oscillatory motions at low inflow and in the presence of free stream speed fluctuations.

VISITS/COMMUNICATIONS

I. J. I. Craig

Naval Air Development Center, Warminster, PA, August 10, 1983

The visit was arranged by J. J. Minecci of their structures group. A short presentation of our activities within our Center of Excellence was given to a small, interested group. Extended discussions were had with Clarence M. Chen about NADC's interests in the rotary wing aircraft area. The visit included a tour of their structural test facilities with considerable discussion of their composites work.

Sikorsky Aircraft, Stratford, CN, August 11, 1982

The visit was arranged through Nick Lappos who set up meetings with the heads of the aero-mechanics, structural dynamics, and structures groups. Our planned activities within the Center of Excellence were presented and considerable discussion was centered on areas of mutual interest.

II. J. I. Craig and S. V. Hanagud

NASA-Langley, October 5, 1982

The visit was with Jim Starnes and Marshall Rouse to view their test fixtures and specimens used to conduct post-buckling studies of graphite-epoxy panels. The information received will be of great value in planning the tests to be conducted as part of our Structures Task 2 research.

USARTL, Ft. Eustis, VA, October 5, 1982

The visit was with Nick Calapodas and included an extensive tour of the laboratory facilities and discussions of their overall structural dynamics program. The visit was quite informative and will allow us to plan our Structures Tasks 1 and 2 research to complement the Army work.

U. S. Army Aviation Safety Division

Contact has been made with Dr. James Hicks. At present, arrangements are being made through Dr. Robert Singleton to obtain information concerning key problem areas in the crashworthy performance of helicopters.

III. R. B. Gray

USARTL, Ft. Eustis, VA, July 22, 1982

Mr. Bill Pleasants was visiting the Lockheed-Georgia Co. and stopped by Georgia Tech. We discussed the planned activities within the Center of Excellence and other mutual interests.

Hughes Helicopters, Tempe/Mesa, AZ, November 2-3, 1982

The visit was in response to their invitation to attend their IRAD Review for the Government. The visit was very valuable in that it provided the opportunity to meet and talk with Army and Industry personnel and to learn about research concerns and directions as they relate to our program.

National Institute for Aeronautics and Systems Technology, Pretoria, South Africa, November 19, 1982

Dr. A. J. van Wyk had read about the Centers of Excellence in Vertiflite and arranged to visit them when he was in this country. He was given a tour of the facilities and met with most of the involved faculty. He was interested in exploring the possibility of sending their personnel here for training or of having some of our faculty go there to present short courses in the rotary wing field.

USARTL, Langley Field, VA, December 14 -15, 1982

The visit was in response to an invitation from Mr. Richard Long to attend a review of the UTRC Helicopter Aerodynamics Research with Emphasis on Rotor Wake Geometry and Its Influence in Forward Flight which was presented by Alan Egolf and Jack Landgrebe of UTRC. The visit provided an invaluable opportunity to learn the details of this research and to discuss the area in depth with Army/NASA/UTRC personnel since some of our research has a close relationship. Dr. Warren Young gave me a tour of the helicopter model testing facilities and we were able to discuss areas of mutual interest.

University of Maryland, College Park, MD, December 16, 1982

Dr. Allen Plotkin telephoned to discuss and request information on our academic program and some of our courses. The requested material was mailed to him.

USARTL, Moffett Field, CA, December 16, 1982

Drs. Fredric Schmitz and Chee Tung visited our Center. They were particularly interested in our aerodynamics facilities and research programs. They met and discussed program details with A. L. Ducoffe, J. E. Hubbartt, H. M. McMahon, J. C. Wu, and me. Their interest and comments were very much appreciated.

IV. R. B. Gray, S. V. Hanagud, and G. A. Pierce

Headquarters, AVRADCOM, St. Louis, MO, Nov. 30 - Dec. 1, 1982

This was the initial review of the Centers of Excellence. It was a very informative meeting and much benefit was gained to learn of the activities of the laboratories and other centers. Of particular importance was the discussion of areas of mutual interest and the helpful comments.

V. G. A. Pierce

USARTL, Langley Field, VA, December 9, 1982

Various members of the Rotorcraft Aeroelasticity Group of the Configuration Aeroelasticity Branch were visited to discuss their current programs in the fields of aeroelasticity, unsteady aerodynamics, and structural dynamics.

USAATL, Ft. Eustis, VA, December 10, 1982

The purpose of the visit was to discuss current programs and interests in rotorcraft technology with Dr. C. E. Hammond, Chief of the Aeromechanics Technical Area and with Mr. Nick Calapodas who is responsible for their inhouse structural dynamic testing facility.

VI. J. C. Wu

USARTL, Moffett Field, CA, July 22, 1982

The visit was with personnel in the Aeromechanics Laboratory and various technical topics in unsteady aerodynamics were discussed with Drs. Larry Carr, Frank Caradonna, Chee Tung, and Ken McAllister. Dr. Wendell Stephens was also visited. During the reporting period, telephone conversations were held with Dr. Chee Tung.

University of Maryland, College Park, MD

Dr. Allen Plotkin telephoned to discuss our research and course offerings in computational fluid dynamics.

PAPER ABSTRACTS

I. METHOD OF MULTIPLE SCALES AND IDENTIFICATION OF NONLINEAR STRUCTURAL DYNAMIC SYSTEMS

S. V. Hanagud, M. Meyyappa, and J. I. Craig

AIAA, AHS, ASCE, ASME 24th Structures, Structural Dynamics and Materials Conference, Lake Tahoe, CA, May 1983

A procedure has been developed to identify the parameters of a nonlinear structural dynamic system with a single degree of freedom. A cubic nonlinearity has been assumed for purposes of illustration. In comparison to the direct identification procedures that depend on: (a) either the availability of data on all four variables, namely, velocity, acceleration, displacement and the input to the system or (b) the formulation of a numerical algorithm that can be used at each iterative step, the developed procedure requires the data on only one of the field variables. The input to the system is also treated as an unknown. The results from the perturbation identification procedure has been compared with the results from two direct identification procedures.

II. A COMPARISON OF FINITE DIFFERENCE SCHEMES FOR SECOND PIOLA-KIRCHHOFF FORMULATION

S. V. Hanagud and N. S. Abhyankar

International Symposium on Numerical Methods, Paris, France
March 16-18, 1983

Finite deformation transient dynamic response problems have been formulated by using second Piola-Kirchhoff stresses. Five different second order accurate finite difference schemes have been used to solve these problems. These different schemes have been compared for their computational efficiency and dispersion errors. In particular, elastic, elastic-plastic and nonlinearly compressible materials have been used to compare the different schemes numerically.

PROGRESS REPORT

(TWENTY COPIES REQUIRED)

1. ARO PROPOSAL NUMBER: 19364-E

2. PERIOD COVERED BY REPORT: 1 January - 30 June 1983

3. TITLE OF PROPOSAL: A CENTER OF EXCELLENCE IN ROTARY WING AIRCRAFT TECHNOLOGY

4. CONTRACT OR GRANT NUMBER: DAAG29-82-K-0094

5. NAME OF INSTITUTION: School of Aerospace Engineering
Georgia Institute of Technology

6. AUTHOR(S) OF REPORT: R. B. Gray (Principal Investigator), J. I. Craig, S. V. Hanagud, J. E. Hubbartt, N. M. Komerath, S. G. Lekoudis, H. M. McMahon, G. A. Pierce, & J. C. Wu

7. LIST OF MANUSCRIPTS SUBMITTED OR PUBLISHED UNDER ARO SPONSORSHIP DURING THIS PERIOD, INCLUDING JOURNAL REFERENCES:

(See attached)

8. SCIENTIFIC PERSONNEL SUPPORTED BY THIS PROJECT AND DEGREES AWARDED DURING THIS REPORTING PERIOD:

Faculty: J. I. Craig, A. L. Ducoffe, R. B. Gray, S. V. Hanagud, J. J. Harper, J. E. Hubbartt, S. G. Lekoudis, H. M. McMahon, G. A. Pierce, & J. C. Wu

Research Engineers: S. Kleinhaus & N. Sankar

Research Associates: J. Caudell, H. Meyer, & D. Ransom

Fellows: Thomas M. Boyd, Cynthia P. Boyette, Kathryn D. Dunlop, Thomas C. Parham, Gregory D. Power, & Thomas L. Thompson

Graduate Research Assistants: V. R. P. Jonnalagadda, J. W. Rogers, P. Siram, & T. C. Wey

Degrees Awarded: CPT. W. S. McArthur, U. S. Army, Master of Science, March 1983

Dr. Robin Gray 19364-E
Dr. A. L. Ducoffe
Georgia Institute of Technology
School of Aerospace Engineering
Atlanta, GA 30332

7. List of Manuscripts Submitted

a) Method of Multiple Scales and Identification of Nonlinear Structural Dynamic Systems. S. V. Hanagud, M. Meyyappa, and J. I. Craig.

b) A Comparison of Finite Difference Schemes for Second Piola-Kirchoff Formulation. S. V. Hanagud and N. S. Abhyankar.

c) A Mixed Method for Layered Isotropic Plates. S. V. Hanagud, S. Chandrashekara, and R. Chander.

d) Structural Dynamic Physical Models of Helicopters by Identification Technique. S. V. Hanagud, M. Meyyappa, and J. I. Craig.

RESEARCH TASKS

I. Aerodynamics

Task I. Experimental Studies for Tip Vortex Core Modelling
R. B. Gray

The objective for this investigation is to obtain data for guiding the development of a tip vortex core model to use in free wake analyses for predicting helicopter blade loadings. A laser doppler velocimeter data acquisition system is being acquired for this purpose. The status of this system is described in the Facilities/Equipment Section of this report. In accordance with the original proposal and approved budget, the system will not be fully operational until the second year of the contract.

Task 2. Modification of Blade Tip Loading to Improve Hovering Figure of Merit
R. B. Gray

The dominant feature of the tip pressure distribution on a hovering model rotor blade is the low pressure region associated with the roll-up and rearward sweep of the tip vortex over the trailing 50% of the blade upper surface. This pressure distribution contributes significantly to the rotor power. The objective of this task is to investigate the feasibility of modifying the pressure distribution to improve performance.

The test configuration has three small winglets mounted near the leading edge of the blades on the square, flat tip surface. The winglet span and incidence angle are varied. A considerable range of span and incidence angle variation has been tested. There have been some instrumentation problems which are being checked out. These problems will be corrected and testing will continue.

Task 3. A Procedure for Computing Rotor-Blade/Tip-Vortex Interactions
R. B. Gray and S. G. Lekoudis

An iterative lifting surface method has been developed for computing the surface pressure distribution in hover on a thick rotor blade with a half-body of revolution tip. A comparison of the results in the tip region with experimental data shows that the method yields good agreement on the lower surface and on the upper surface near the leading edge where the tip relief effect predominates. However, the method does not satisfactorily predict the pressure distribution associated with the rearward sweep of the tip vortex over the upper surface aft of the 50% chord station. Therefore, the objective of this investigation is to study simplified flow models which may lead to better results in this region.

The basic viewpoint underlying the development of this method was to assess the viability of an inviscid, incompressible flow model with the implied classical theorems while employing empiricisms which appear to be reasonable well accepted. For example, it is required: that the computed and measured thrust be in close agreement; that the maximum bound vortex and the fully developed tip vortex strength be in close agreement; that the tip vortex geometry be prescribed and correspond with that measured for a rotor having the same thrust coefficient and number of blades; and, a questionable but necessary empiricism, that the effect of Reynolds number can approximately be accounted for by adjusting the blade pitch angle. The one major inconsistency from the classical viewpoint is that no attempt is made to model or require vortex filament continuity from the blade surface to the tip vortex. The major unknowns are the geometry of what might be called the central curve and the local strength of the tip vortex as it develops and sweeps rearward over the blade.

In the previous reporting period, it was assumed that the prescribed tip vortex geometry began just off the blade trailing edge and numerical experimentation was employed to extend the central curve of the tip vortex forward over the blade to about the quarter-chord point. A trial and error process was used first with both a linear and a quadratic variation in tip vortex strength. The result was reasonable good agreement with the measured pressure distribution.

During this reporting period, iterations were performed on the "trial and error" geometry to find the "free" geometry. The geometry did not change much in these iterations and the results were similar. In a second study using this last computed geometry, the vortex strength growth rate and the match point with the empirically prescribed wake were varied. The results showed a sensitivity to both growth rate and the location of the match point. The third study used the same geometry and investigated the effect of vortex strength overshoot; e.g. the strength grows to a value larger than the maximum bound strength and then reduces to this maximum value at the match point. The agreement was good for both the 99.1% and the 99.5% radius station but was still poor further inboard. A larger overshoot in strength was used and the results showed that the amount of overshoot was less important than the strength growth rate. The last study was to eliminate some of the arbitrary assumptions. The blade pitch angle was adjusted to more closely maintain the corresponding measured thrust, the tip vortex strength was adjusted each iteration, the strength growth rate was computed from the surface vorticity distribution, and the inner sheet geometry was recomputed for each iteration. The results were poorer than for some of the other studies.

The long term objectives of this task include the capability of obtaining solutions for the flow around a blade tip without empirical input. The following paragraphs describe some efforts expended towards achieving this objective.

It is anticipated that part of the next generation of military helicopters will have higher speeds in forward flight. Therefore compressibility effects in the transonic flow around the tip will be more pronounced. Viscous flow solutions for the flow around the blade should account for compressibility effects, especially if the interest is in designing new tip shapes. A three-dimensional Euler solver was developed and tested. The two-dimensional version of the code was tested by comparing with similar calculations done at NASA-Ames. The agreement was excellent. The three-dimensional code was executed on several computers at Georgia Tech in search for the best economy in computer resources. The computers were a CYBER 760, an IBM 4341 and an HP 1000. The small memory of the CYBER 760 necessitated changes in the algorithm and the speed of the HP 1000 precludes any use of the system for three-dimensional calculations. The original algorithm was based on an approximate factorization scheme that leads to block tridiagonal inversions in each space direction. The code uses an implicit finite-difference algorithm with time-stepping. Coarse grid calculations for a NACA 0012 wing showed qualitatively the appropriate behavior at the tip with the formation of the tip vortex. In search for a faster algorithm, requiring less storage, a hybrid code was written with the implicit ADI algorithm retained in the airfoil planes and with explicit treatment of the spanwise direction. Considerable computer resources are required to run the code, and that necessitates extreme care in the selection of runs. As an example, 500 time steps require more than 24 hours of processing on the IBM 4341. A reasonably dense grid requires about half a million words of memory.

More runs of a two-dimensional viscous/inviscid interaction code (GRUMFOIL) were made in order to answer the following question: (see also Progress Report, January 1983) How well can a pressure distribution on a blade in hover be predicted by a two-dimensional viscous theory? The comparisons with the data of Gray et. al showed that reasonable agreement is obtained for stations as far out as 94% of the span. The calculation underpredicts the C_p distribution on the top midsection of the blade but the sensitivity of the prediction to the effective angle of attack is very large. Because of the previously established reliability of the calculation procedure, the importance of the tip vortex on the angle of attack becomes great if one wants to use the calculation for other blade section shapes. Otherwise a three-dimensional boundary layer calculation seems absolutely necessary in order to accurately predict the viscous effects on the pressure distribution in hover, at least for the NACA 0012 blade section.

The three-dimensional Navier-Stokes code, written by Shamroth of Scientific Research Associates, was obtained from NASA-Langley. However the code is hardwired for Langley's CDC 205 and, therefore, it is impossible to run it on another computer. After discussions with Warren Young at Langley, user guides for the unsteady wing codes (panel codes) developed by Analytical Methods were obtained. These codes will be obtained from Langley.

As part of the effort to develop viscous prediction methods for unsteady flows around the blade, an unsteady two-dimensional, turbulent boundary layer code for incompressible flow was tested as part of an M.S. special problem. The code uses an algebraic eddy-viscosity model and the Keller-box finite-difference method.

Task 4. Studies of Unsteady Rotor Aerodynamics
J. C. Wu and N. L. Sankar

The two-dimensional viscous airfoil code developed during the preceding reporting period was utilized in computing a laminar unsteady viscous flow past a NACA 0012 airfoil undergoing the following pitching motion about the quarter chord:

$$\alpha = 10^\circ - 10^\circ \cos t$$

The free-stream Mach number was 0.2 and the free-stream Reynolds number was 5000 in this study. Good quantitative agreements between the present results and results presented by other researchers for this problem were observed.

In addition to the above unsteady flow problem, viscous and inviscid flows past a NACA 0012 airfoil at the following flow conditions were also computed: (i) $M_\infty = 0.72, \alpha = 0$, Inviscid; (2) $M_\infty = 0.63, \alpha = 2^\circ$, Inviscid; (3) $M_\infty = 0.80, \alpha = 0^\circ$, Inviscid; (4) $M_\infty = 0.2, \alpha = 0$, Re = 10000.

The above four problems were chosen because they have in the past been used as standard benchmark cases by other researchers. In all the above cases, excellent agreement was obtained with published results. Currently, work is underway to introduce well-tested eddy viscosity models in the airfoil code. Some preliminary work is also underway to incorporate the multigrid concept of Brandt in the present code. The multigrid concept is expected to reduce significantly the number of time steps needed to achieve converged steady state solutions.

A three-dimensional Euler code, written during the previous reporting period, has also been checked out during this reporting period. This program can handle large and small aspect ratio fixed and rotary wings of arbitrary plan form including rotary wings with highly swept tip regions. This program has thus far been tested only for fixed wing geometries. A moderate aspect ratio ONERA M6 Wing widely used by other CFD researchers as a standard benchmark geometry was used in the present studies. The freestream Mach number and the angle of attack were 0.923 and 0° respectively. Very good agreement with experimental results was obtained for this flow condition. Currently, effort is underway to add the viscous terms to the code. With the addition of the viscous effects the code should prove useful in studying useful concepts such as circulation control. This code is competitive with other existing three-dimensional Euler solvers and requires about 4 hours on a CYBER 835 Computer to arrive at a steady state solution for a particular geometry and flow condition on a 65 x 13 x 12 grid.

Task 5. Studies of the Airframe Flow Field in Forward Flight
James E. Hubbartt and Howard M. McMahon

During this period we have completed 1) fabrication and assembly of the rotor support, drive, and control systems, 2) acquisition of the test instrumentation, and 3) design of the rotor, the fuselage model, and the model support systems. Also, we have issued work orders for fabricating the fuselage and rotor models and initated the check-out and packaging of the instrumentation. The design is intentionally simple and versatile. It is thought that this will greatly expedite the acquisition of a data base needed to validate and/or develop analytical models. Correspondingly, the facility will have a relatively stiff rotor and make use of simple bodies of revolution to simulate fuselage configurations. Also, the rotor and fuselage model will be mounted separately so as to permit significant variations in rotor and fuselage angles, separation distances, and relative streamwise locations. Provisions are being made for measuring forces and both steady and unsteady surface pressure data on the fuselage model and flow field velocity and pressure data. This will involve the use of surface pressure taps, surface microphones, flow field pressure and hot-wire probes, and the LDV which is discussed separately in this progress report.

In addition, during this period a review of the available techniques for predicting the coupling between the rotor and airframe aerodynamics has continued. It has been decided to focus attention on the analytical models by Carl E. Freeman (NASA TP 1656, 1980) and by David R. Clark and B. Maskew (AHS Annual Forum, 1983). The first priority will be to assess Freeman's model. Later the Clark/Maskew model will be considered. During the latter part of this period, we initiated inquiries regarding the availability and documentation of computer codes for these analytical models.

II. Structures

Task I. Structural Dynamic System Identification
S. V. Hanagud and J. I. Craig

Two lumped mass physical models of a helicopter have been designed. One design is based on state-of-the-art techniques and the other is a proof-of-concept design to explore various simple model construction techniques. The latter design has been fabricated to test these techniques. Preliminary structural dynamic identification tests have been performed. A technique has been developed to design physical structural dynamic scale models from the information available on a given full scale rotorcraft. The developed technique has been applied to design a scale model for a given tail boom. Attempts are also being made to acquire a full scale tail boom for purposes of comparison tests.

Preliminary work has been done in developing techniques for structural dynamic identification of systems with nonproportional damping. The developed technique has been tested for a simple system with three degrees of freedom.

Task 2. Crashworthy Characteristics of Composite Rotorcraft Structures
S. V. Hanagud

Some static post buckling tests of composite sandwich structures, with selected crush zones, have been completed. The complete work included the design and fabrication of the required test fixtures, fabrication of the specimens, quality control tests, panel buckling tests, crush zone tests and sandwich post buckling tests.

Transient dynamic response of a specific crush zone has been studied by using a Cauchy stress formulation with finite deformation. A numerical technique with second order accuracy has been developed and applied to this particular case. Preliminary work has also been done with a reference coordinate formulation. State-space techniques have been formulated and are being applied to the study of vibration of composite sandwich structures with crush zones. Dynamic test facilities have been designed.

III. Aeroelasticity

Task I. Helicopter Vibration Suppression Techniques
G. A. Pierce

This program is intended to develop and validate a comprehensive vibratory loads analysis for the design evaluation of vibration suppression techniques. The loads analysis will be applicable to nonuniform multi-bladed systems with teetering, articulated, hingeless or bearingless hub constraints. Special emphasis will be placed on blade structural dynamics, hub and mast dynamics, impedance of the rotor/airframe interface, and unsteady blade aerodynamics. The vibration suppression techniques to be considered will include higher harmonic pitch control, blade-mounted absorbers, hub-mounted absorbers, and aeroelastic tailoring.

The vibratory loads analysis as initially formulated is a discrete frequency harmonic analysis which yields a complete solution to the governing differential equations of a multi-bladed rotor system. A transfer matrix representation is utilized to simulate the structural dynamic characteristics of the nonuniform blades in a continuous manner. Consequently no approximations are introduced into the mathematical model as with modal lumped parameter and finite element representations. The mesh fineness of the integration routine used for solving the simultaneous governing equations is the only source of solution error. These equations include flap, lead-lag and torsional degrees of freedom with the effects of mass-elastic axes offset, prepitch, pretwist and precone.

Although the blade-root boundary conditions are currently restricted to hingeless configurations, they provide the mechanism for incorporating the hub dynamics and simulation of fuselage structural dynamic behavior. This is accomplished by utilizing a complex frequency-dependent compliance matrix to passively simulate the dynamic mast/fuselage properties. The hub dynamics are influenced by this matrix and the blade root reactions based on an apriori specification of the interblade phase relations. The resulting motion of the hub in turn provides the displacement components of the blade root. Since these dynamical equations of the rotor hub are linear, it has been possible to formulate a matrix representation for the blade-root displacement components in terms of the blade-root load components.

FACILITIES/EQUIPMENT

I. Laser Doppler Velocimeter Data Acquisition System
R. B. Gray, J. E. Hubbartt, H. M. McMahon, & N. M. Komerath

The optics and electronics modules for measuring one component of velocity were assembled and checked out. The three-axis optical traverse system was received in late May, assembled, and checked out. The HP 1000 computer system was installed in the Nine-Foot Static Thrust Facility and interfaced to the LDV counter processor and the traverse system. A model atomizer seeder was built and seeding using water particles was demonstrated in a free jet. The one-component LDV system was moved into position to measure the tip vortex from the rotor in the Nine-Foot facility.

Data processing software was developed in the School in a joint effort with research teams working in fluid mechanics and turbulent combustion. Company-supplied data-interfacing routines were used as the starting point for a FORTRAN package which now includes the capabilities to transfer data directly into the computer memory, and convert it into a velocity-time matrix from which the mean values, root-mean-square fluctuations, Reynolds stresses, histograms, and joint probability density function are evaluated. Velocity-bias corrections can be performed. Results are displayed using HP graphics routines on a video screen or on hard copy. An interactive program for computer control of the traverse system is in operation. The software package has been extensively used on a two-component LDV in the School's fluid mechanics laboratory to process data from turbulent recirculating flows and jet flames.

An interface has been installed between a rotor shaft encoder and the LDV counter processor to enable rotor-synchronized averaging of the data. Tests have begun on data acquisition from the flow downstream of a spinning rotor. The second component of the LDV system is expected to be on order shortly. Software development is under way on routines for time-series analysis of LDV data and for improved storage, display, and processing capabilities.

II. Nine-Foot Static Thrust Facility
R. B. Gray

The facility was designed to provide a laboratory-controlled environment for testing model helicopter rotors up to 4½ feet in diameter in hovering flight. This facility is to be updated over a period of several years. The modifications have been scheduled to permit some interim testing.

The LDV system will have its first use in this facility and the progress in this area is described above. The mercury slipring assembly was scheduled to be reconditioned during this period but this will be delayed to permit some testing to continue. A new balance system and data acquisition system is planned for later years.

III. Structural Dynamic System Identification Facility
S. V. Hanagud & J. I. Craig

No significant facility developments are planned for the first year.

IV. Transient Dynamic Stress Analysis Facility
S. V. Hanagud

Although some preliminary design has been done and instrumentation evaluated, the facility development is scheduled for the next year.

V. Nine-Foot Wind Tunnel Facility
J. J. Harper, J. E. Hubbartt, H. M. McMahon, S. Kleinhaus, & N. Komerath

During this period, two contracts have been signed for modification of this facility. The first involved structural steel work for the rotor drive support above the test section and for a rigid platform beside the test section to support the laser velocimeter. This work has been completed. A second contractor has begun construction on the next phase involving new instrumentation wiring and the enclosing and air-conditioning of the control room.

The design of the Lockheed-funded flat floor and ceiling is almost complete and fabrication has started. Necessary modifications to an existing probe actuator have been noted and the ceiling design has been modified in order to accommodate this actuator.

As instrumentation is received, it is being installed in racks so that a new operating console can be assembled as soon as the control room renovations are completed.

A study of safety barriers for the forward flight facility has been made during this period and the containment structure has been designed.

VI. Sixteen-Foot Rotor-Test Facility Development
G. A. Pierce, R. B. Gray, & S. S. Kleinhaus

This new test facility will accommodate model rotor systems of eight foot diameter. Currently planned test programs include dynamically excited aeroelastic models for vibratory loads studies and rigid models for both steady and unsteady aerodynamic measurements.

Detailed design of the facility has been finished and construction is approximately seventy percent complete. The thrust stand to support the drive system and conical shaft support has been built and is awaiting delivery of the drive shaft. The cylindrical shroud and containment structure have been erected and the honeycomb panels are being installed. An acoustically insulated control room has been assembled beneath the drive system platform and is awaiting the electrical contractors for installation of the electrical service and air-conditioning. All remaining items for operation of the facility have been ordered except for the data acquisition system and model rotor system.

NEW COURSE DEVELOPMENT

The development of the following courses has begun or is complete. The development of the remaining new courses has been scheduled for a later reporting period.

I. System Identification
S. V. Hanagud and J. I. Craig

This course is concerned with an introduction to the techniques of identification of structural dynamic systems. The course outline, preparation of some lecture notes, design of laboratory tests, and certain computer programs have been completed. It is planned to offer the course during the Summer or Fall quarters of 1984.

II. Finite Deformation of Aircraft Structures
S. V. Hanagud

A course outline has been prepared and work on arranging the lecture material is continuing. The completion of this course is scheduled for the next year.

III. Computational Aerodynamics
S. G. Lekoudis

This is an introductory course in computational aerodynamics. The course outline has been prepared and the lecture notes are complete. It will be offered during the next academic year.

IV. Viscous Flow III
S. G. Lekoudis

This course covers the modelling of turbulent flows. The development is complete and is being taught during the Summer quarter of 1983.

V. Numerical Fluid Dynamics III
J. C. Wu

Continued efforts have been devoted to the development of the above titled new course. Plans are being made to offer this course in the Fall quarter of 1983. This new course is designed to acquaint the students with state-of-the-art engineering applications of computational aerodynamics. Studies of rotors and wakes with applications in rotary wing aircraft analyses will be a part of the course.

UPDATED COURSES

I. Advanced Compressible Flow Theory II
N. L. Sankar

This course has been modified to include material on transonic flow on helicopter blades in forward flight. It was taught in the Spring quarter of 1983.

II. Advanced Potential Flow I & II
G. A. Pierce

The modification of these courses was completed during the last reporting period by adding material on phenomena that is unique to helicopter rotor blades. The added material includes topics on blade oscillatory motions at low inflow and in the presence of free stream speed fluctuations. These courses were taught in the Fall quarter of 1982 and the Winter quarter of 1983, respectively.

III. Advanced Aeroelasticity I
G. A. Pierce

The modification to this course has been completed by adding material which is unique to helicopter systems. The added material includes topics on stability analyses of linear systems with periodic coefficients and dynamic load suppression techniques based on absorbers, isolators, and harmonic control. This course was taught during the Spring quarter of 1983.

IV. Experimental Aeroelasticity
G. A. Pierce

This course has been modified to include testing techniques which are unique to the development and evaluation of helicopter configurations. These techniques include the measurement of mobility, inertance, and compliance matrices for use with anti-resonance theory and the moving block analysis of transient responses for the identification of damping characteristics. This course is being taught in the Summer quarter of 1983.

VISITS/COMMUNICATIONS

I. R. B. Gray

Georgia Power Company, January 7, 1983

A telephone call was received from Mr. George Dickens, Industrial Development Division. He has heard about our C. O. E. and wanted some information to include in their package of material which is used to attract industry to Georgia. Written material and several slides were sent.

USARTL, Moffett Field, CA, January 13, 1983

A telephone call and a letter were received from David L. Key, Chief, Flight Control Division, inquiring about availability of B.S., M.S., and Ph.D. graduates for employment. Inquiries within the School were not successful.

AVRADCOM, St. Louis, MO, January 27, 1983

A telephone call was received from Dr. Harold Y. Law concerning a display booth on our C. O. E. activities at the AHS Forum in St. Louis in May. The faculty met and, after discussion, agreed to proceed. Several telephone calls were made to AHS Headquarters, Dr. Robert Loewy, RPI, and Dr. Al Gessow, U. of Maryland, to coordinate this activity.

Boeing Vertol Company, Philadelphia, PA, February 2, 1983

Mr. Euan Hooper, Director of Vehicle Technology and Membership Chairman of AHS, visited our Center. We discussed involvement with AHS activities, quality and availability of students seeking employment, and research of mutual interest.

I. R. B. Gray (Continued)

Hughes Helicopters Inc., Culver City, CA, February 15, 1983

Dr. Dave Banerjee, Chief, Aeromechanics Research & Development, visited our Center. He presented a seminar on the programs and job opportunities at Hughes.

Hughes Helicopters Inc., Culver City, Ca, February 15, 1983

A telephone call was received from Mr. Dean C. Borgman, Director, R&D, concerning our C. O. E. program. There was considerable discussion about ways for interacting. Information on our Center and graduate programs were sent.

United Technology Research Laboratories, Hartford, CN, March 9, 1983

A telephone call was received from Jack Landgrebe, Manager, Aeromechanics Research, concerning availability of students for employment. Names were given for him to contact.

Indian Institute of Science, Bangalore, India, March 15, 1983

Dr. A. K. Rao, Professor of A. E. visited our Center to discuss research and matters of mutual interest.

-----------------------, March 15, 1983

A telephone call was received from Mr. Troy Simmons who said that he had a helicopter design ready for manufacture and needed financial advice and backing. He was referred to the Georgia Tech Advanced Technology Development Center.

Benson Aircraft Corporation, Raleigh, NC, March 16, 1983

Dr. Igor Benson, Chief Executive Officer, visited our Center to discuss matters of mutual interest.

Boeing Vertol Company, Philadelphia, PA, March 30, 1983

A telephone call was received from Mr. Euan Hooper, Director of Technology, inquiring about Georgia Tech's Cooperative Program and wanting to know about details of starting a program. I referred him to the Cooperative Division.

Analytical Methods Inc., Bellevue, WA, March 31, 1983

Dr. Michael Summa visited our Center. He presented a seminar on the computational fluid mechanics projects at Analytical Methods and the codes that they have developed and are available. Individual discussions on research matters were held with Gray, Hubbartt, McMahon, Lekoudis, Sankar, and Wu.

Sikorsky Aircraft Division UTC, Stratford, CN, April 4, 1983

A telephone call was received from Mr. Ted S. Carter, Director of Technology, inquiring about the possibilities of a graduate cooperative program. This was discussed at some length. They are also interested in summer employment of our B.S. graduates. Mr. Raymond Bruttomesso, Class of '83, is working at Sikorsky this summer and will begin some research in composite materials which will be continued under Dr. Rehfield's guidance after Mr. Bruttomesso returns to Georgia Tech this fall to enter our M. S. program. (The Graduate Division at Georgia Tech is currently exploring the possibilities of starting a graduate cooperative program.)

USARTL, Langley Field, VA, April 7, 1983

Mr. Richard Long, Director, Structures Laboratory, visited our Center. He was given a tour of our structures facilities and discussed Center activities with J. I. Craig, R. B. Gray, S. V. Hanagud, and L. W. Rehfield.

Army Aviation Association of America Convention, Atlanta, Ga., April 9, 1983

Mr. Arthur H. Kesten, General Chairman, 1983 National Convention, provided complimentary access to the Exhibit Hall. Several faculty members and students saw the exhibits.

USARTL, Langley Field, VA, April 20, 1983

Dr. Larry Roderick, Chief, Army Aeronautical Research Group, Structures Laboratory, visited our Center and presented a seminar to the faculty and students. He also had individual or group discussions with all of the faculty involved in our C.O.E.

USARTL, Moffett Field, CA, May 5, 1983

A telephone call was received from Dr. Jim McCrosky, Senior Staff Scientist, concerning availability of our students for employment. Inquiries within our School were not successful.

AHS 39th Annual National Forum, St. Louis, MO, May 9-11, 1983

A display booth in the Exhibit Hall was set up and manned by R. B. Gray, G. A. Pierce, and S. S. Kleinhaus. Valuable contacts were made and interesting technical discussions were held with other attendees.

USARTL, Langley Field, VA, May 16 and 23, 1983

Telephone calls were made to and received from Dr. Warren Young, Group Leader, Structures Laboratory, concerning availability of computer codes. Dr. Young was very helpful and provided names of personnel to be contacted.

Hughes Helicopters Inc., Culver City, CA, May 26, 1983

A telephone call was received from Mr. Robert J. King, chief of Acoustics, concerning the availability of students for employment. Two B. S. graduates, Class of '83, were interested and one was employed.

I. R. B. Gray (Continued)

US Army Aviation Center and Fort Rucker, June 3, 1983

MG Carl H. McNair, Jr., Commanding General, was the featured speaker at the Annual Aerospace Engineering Senior Dinner. On June 4th, a briefing on the Center's activities was presented by Professors Gray, Hanagud, Hubbartt, and McMahon.

Army Evaluation Panel, Atlanta, GA, June 28-29, 1983

Drs. C. E. Hammond, Idelle Peterson, G. L. Roderick, D. P. Schrage, and R. E. Singleton visited our Center and were briefed on our activites. The faculty have been informed of the results of the review and implementation, as appropriate, will proceed.

II. S. V. Hanagud

Finite Element Modelling Workshop for Rotorcraft, Langley Field, VA, February 1-4, 1983

The Workshop was very informative. It provided an opportunity to observe current industry procedures and the problems associated with the finite element programs that are currently in use. Many industrial representatives were met. Our project on structural dynamics system identification was discussed with Mr. A. Bermann and Mr. E. Nagy of Kaman Aerospace Corporation. Our concepts of crushzones and crashworthy characteristics of composite rotorcraft structures were discussed with Mr. Jim Cronkite of Bell Helicopter Textron. Dr. Larry Roderick made arrangements for a visit to the crash test facilities at NASA.

International Conference on Numerical Methods in Engineering, Paris, France, & Aerospatiale Helicopter Facilities at Marignanne, France, March 16-18, 1983

A paper entitled "Second Order Accurate Numerical Techniques and Second Piola-Kirchhoff Formulations" was presented at the Conference. Dr. Hanagud was invited to be on the Executive Committee for the Fourth International Conference on Numerical Methods in Engineering. After the meeting, the structural dynamics and structures group of the Helicopter Division of Aerospatiale were visited. A lecture on our research activities in the fields of structural dynamics and crashworthy designs was delivered. The structural dynamic test facilities, other test facilities, and the manufacturing facilities were visited.

III. J. E. Hubbartt

USARTL, Langley Field, VA

A telephone call was made to Mr. John C. Wilson, Head, Rotor Aerodynamics Office, to begin an exchange of information on rotor/fuselage interference research, to invite Mr. Wilson to Georgia Tech for discussions and a talk to our students and staff in our C. O. E., and to determine the status and availability of the computer code for Freeman's Analysis (NASA TP 1656). Because of limited travel funds, it was not possible for him to accept our invitation during this fiscal year. However, it is possible that Mr. John Berry of his staff would be in Atlanta and could come by. The computer code was in their computer but there was a question as to its accessibility and documentation. Mr. Wilson would check on this.

III. J. E. Hubbartt (Continued)

USARTL, Ft. Eustis, VA

A telephone call was made to Mr. Don Vann, Applied Technology Laboratory, to determine which portions of the computer code developed by David Clark and B. Maskew was supported by the government and if he had access to it and could get it for us. Mr. Vann said that the Army had not supported this recent work and that David Clark should be contacted directly. He said that the Army had supported David Clark in developing a "Drag Computer Code" which they had and should be available to us on request.

USARTL, Ft. Eustis, VA

A letter was written to request the above computer code and this is still in process.

IV. G.A. Pierce

Bell Helicopter Textron, Inc., Ft. Worth, TX, March 2-3, 1983

Dr. Jing G. Yen, Chief Scientist and Chief of Rotor Dynamics visited the Georgia Tech campus. Very informative discussions were held with respect to Bell's current aeroelastic studies. Our programs were discussed and Dr. Yen visited with some of our fellowship and GRA students.

USARTL, Langley Field, VA, March 11, 1983

Dr. M-Nabil H. Hamouda of the AVRADCOM Structures Lab visited the Georgia Tech campus. Comprehensive discussions were held on the current state-of-the-art in aeroelastic coupling associated with helicopter analyses. It was generally concluded that a research program in the area of linear unsteady aerodynamics should be initiated to better define aerodynamic coupling.

USARTL, Ft. Eustis, VA, March 31-April 1, 1983

Dr. C. Eugene Hammond, Chief of the Aeromechanics Technical Area of the Applied Technology Lab visited the Georgia Tech campus. In addition to discussing our current aeroelastic programs, Dr. Hammond presented a seminar to the faculty and student body of the Aerospace Engineering School entitled, "Rotorcraft Research at the Applied Technology Laboratory." He also visited with some of our fellowship and GRA students.

AIAA/ASME/ASCE/AHS 24th Structures, Structural Dynamics, and Materials Conference, Lake Tahoe, Nevada, May 2-4, 1983

A paper coauthored by Dr. Anand Vaidyanathan and entitled "A Discretized Asymptotic Method for Unsteady Helicopter Rotor Airloads" was presented. This paper was not supported by this contract. Many interesting technical discussions were held with other attendees.

IV. G. A. Pierce (Continued)

AHS Annual Forum, St. Louis, MO, May 7-11, 1983

An exhibit booth was set up and manned during the Forum. The theme of the exhibit was how the past 50 years of helicopter research at Georgia Tech led to the current CERWAT Program. Numerous copies of brochures on the program, supporting facilities, and curriculum were distributed to the attendees and many technical discussions were held with other researchers.

Stanford University, Stanford, CA, June 1, 1983

In response to a request by Ms. Valana L. Wells of the Department of Aeronautics and Astronautics, copies of three reports (NASA CR 165742, 166092 and 166093) were sent to her which describe our recent work using matched asymptotic expansions to compute the unsteady airloads on a helicopter blade.

NASA Research Center, Langley Field, VA, June 10, 1983

Mr. Ernest W. Millen of the Flight Management Branch, FCSD, was visited. Lengthy discussions were held regarding technological deficiencies which currently exist in the area of inflight wind shear detection. It was generally concluded that a correlation study be conducted to evaluate flight vehicle dynamic response in a wind shear environment.

USARTL, Langley Field, VA, June 10, 1983

Mr. John C. Wilson, Chief of the Rotorcraft Aerodynamics Office, LSAD, was visited. As a member of the AVRADCOM Structures Lab in the Low Speed Aerodynamics Div., it was anticipated that Mr. Wilson would be concerned with developments in the area of unsteady helicopter airloads. Our discussions indicated that he was only concerned with aerodynamics from the standpoint of helicopter performance.

USARTL, Moffett Field, CA, June 21-22, 1983

The ITR Methodology Assessment Workshop was attended. This workshop was jointly sponsored byAVRADCOM (Aeromechanics and Applied Technology Labs) and NASA (Aeronautics and Flight Systems). Industry and government correlation studies were presented and discussed on the topic of aeroelastic rotor stability in both hover and forward flight. This workshop represented the most comprehensive comparative evaluation of aeroelastic analysis capability which the helicopter industry has ever undergone.

V. J. C. Wu

USARTL, Moffett Field, CA, January, 1983

The Army Aeromechanics Laboratory was visited. Various technical topics in unsteady aerodynamics were discussed with Drs. Larry Carr, Frank Caradona, Chee Tung, and Ken McAlister.

ADVISORY BOARD

An attempt was made to schedule a meeting of the Advisory Board in early June. Because of conflicts with other activities of some of the Board members, it was necessary to postpone the meeting. A second attempt will be made to schedule the meeting in late summer.

GRADUATE EMPLOYMENT

Two Bachelor of Aerospace Engineering graduates who took one or more of the helicopter courses were employed by helicopter companies.

John E. Corban - Hughes Helicopter Inc.

Philip L. Elliott III - Boeing Vertol Company

ABSTRACTS

I. METHOD OF MULTIPLE SCALES AND IDENTIFICATION OF NONLINEAR STRUCTURAL DYNAMIC SYSTEMS

Sathya V. Hanagud, M. Meyyappa and James I. Craig

A procedure has been developed to identify the parameters of a nonlinear structural dynamic system with a single degree of freedom. A cubic nonlinearity has been assumed for purposes of illustration. In comparison to the direct identification procedures that depend on, (a) either the availability of data on all four variables, namely, velocity, acceleration, displacement and the input to the system, or (b) the formulation of an algorithm that is used to numerically integrate the differential equation at each iterative step, the developed procedure requires the data on only one of the field variables and no numerical integration at each step. The input to the system is also treated as an unknown. The results from the perturbation identification procedure have been compared with the results from two direct identification procedures.

II. A COMPARISON OF FINITE DIFFERENCE SCHEMES FOR SECOND PIOLA-KIRCHHOFF FORMULATION

Sathya V. Hanagud and N. S. Abhyankar

Finite deformation transient dynamic response problems have been formulated by using second Piola-Kirchhoff stresses. Five different second order accurate finite difference schemes have been used to solve these problems. These different schemes have been compared for their computational efficiency and dispersion errors. In particular, elastic, elastic-plastic and nonlinearly compressible materials have been used to compare the different schemes numerically.

III. A MIXED METHOD FOR LAYERED ISOTROPIC PLATES

S. V. Hanagud, S. Chandrashekara and R. Chander

A mixed method of elasticity known as state space approach is presented for solving the linear elastodynamic problem of layered isotropic plates in plane strain. The interlayer traction and displacement continuities are exactly satisfied while reducing a general three-diminsional problem to one of two diminsions by the present approach. The results obtained for a single layer and two-layered isotropic plates are compared with those obtained by the solution of the exact elastodynamic equation governing the problem.

IV. STRUCTURAL DYNAMIC PHYSICAL MODELS OF HELICOPTERS BY IDENTIFICATION TECHNIQUE

Sathya V. Hanagud, M. Meyyappa and J. I. Craig

At present, a reliable procedure for obtaining the vibration and structural dynamic response of a given helicopter uses flight test information. Such a procedure is expensive and is not available for design analysis. An alternate approach under development for the past few years is the formulation of analytical models (1,2) that can accurately predict the structural dynamic response of the helicopters. The state-of-the-art of the development of such mathematical models employs finite element techniques. In many cases, the NASTRAN program has been used to develop the models. Most of the developed models have been for airframe-only conditions (1,2). In spite of the simplicity of considering only the airframe, the developed mathematical models yield results that do not agree with structural dynamic test results obtained for airframe-only conditions (3,4). Many procedures have been used to modify the mathematical models to achieve an agreement with the results. The modifications that have been based on identification techniques have been further complicated by the presence of complex modes in the test results and approximations in the formulation of the type of finite elements and their stiffnesses.

Therefore, in this paper, another alternate procedure has been presented for obtaining the structural dynamics response of helicopters at the design analysis stage. The procedure depends on the development of a physical scale model. In particular the discussions in the paper are restricted to the design and development of such a physical scale model only.

In general the development of a physical scale model is based on selected objectives that can be achieved by the specific model testing and analysis. In this case the physical scale model will be designed to have the number of frequencies and mode shapes that are the same as that of the complete airframe within certain limits and the degrees of freedom provided in the physical model. Such a model is designed to study the dynamic response under different conditions, including wind tunnel tests.

The steps involved in the development of the physical model are as follows:

* As a first step, a detailed finite element model of the prototype airframe is developed.
* Experimental results are then generated to obtain a specified number of modes and frequencies at the full scale airframe-only level. In this paper, available results have been used.
* The finite element model is then reduced to a smaller degree of freedom where the physical model is to be built. The mathematical model is also scaled down.
* The scaled down mathematical model is then modified by identification procedures to simulate a specific number of modes and frequencies that were obtained in tests.
* The scaled down and identified mathematical model is then translated into the design of a physical model. The physical model consists of lumped masses and some structures containing distributed masses.

The procedure has been illustrated by considering the example of a specific helicopter tail boom.

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1. Cronkite, J.D., et al. "A NASTRAN Vibration Model," US AAMRDL-R-TR-74-045.

2. ___________. "Finite Element Modeling Workshop," NASA Langley Laboratory, 1983.

3. N. Giasonte, A. Berman, W. G. Flannely, E. J. Nagy. "Structural Dynamic System Identification Technology Verification," US AAVRADCOM TR-81-D-28.

4. ___________. "Vibration research Development Plan Summary," AVRADCOM, Langley Research Center, 1980.

PROGRESS REPORT

(TWENTY COPIES REQUIRED)

1. ARO PROPOSAL NUMBER: 19364-E

2. PERIOD COVERED BY REPORT: 1 July - 31 December 1983

3. TITLE OF PROPOSAL: A CENTER OF EXCELLENCE IN ROTARY WING AIRCRAFT TECHNOLOGY

4. CONTRACT OR GRANT NUMBER: DAAG29-82-K-0094

5. NAME OF INSTITUTION: SCHOOL OF AEROSPACE ENGINEERING GEORGIA INSTITUTE OF TECHNOLOGY

6. AUTHOR(S) OF REPORT: R.B. Gray, J.I. Craig, S.V. Hanagud, J.J. Harper, J.E. Hubbartt, S.S. Kleinhaus, N.M. Komerath, S.G. Lekoudis, H.M. McMahon, G.A. Pierce, N.L. Sankar, & J.C. Wu

7. LIST OF MANUSCRIPTS SUBMITTED OR PUBLISHED UNDER ARO SPONSORSHIP DURING THIS PERIOD, INCLUDING JOURNAL REFERENCES:

Structural Dynamic Physical Models of Helicopters by Identification Technique. S.V. Hanagud, M. Meyyappa, and J.I. Craig. Ninth European Rotorcraft Forum, Stresa, Italy, Paper No. 48, Sept. 13-15, 1983

Helicopter Vibration Suppression Using Simple Pendulum Absorbers on the Rotor Blade. M.H. Hamouda & G.A. Pierce, J. of the American Helicopter Society

8. SCIENTIFIC PERSONNEL SUPPORTED BY THIS PROJECT AND DEGREES AWARDED DURING THIS REPORTING PERIOD:

Faculty: J.I. Craig, A.L. Ducoffe, R.B. Gray, S.V. Hanagud, J.E. Hubbartt, S.G. Lekoudis, H.M. McMahon, G.A. Pierce, & J.C. Wu

Research Engineers: S. Kleinhaus, N. Komerath, R. Latham, & N. Sankar

Research Associates: J. Caudell & H. Meyer

Post Doctors: V. Anand, A. Chandrashekara, M. Meyyappa, and C. Wang

Fellows: Ph.D.: Cynthia Boyette, Kathryn Dunlop Engelhardt, Gregory D. Power, & Thomas L. Thompson

M.S.: Thomas M. Boyd, Christopher A. Grimmell, Thomas C. Parham, & Brian E. Wake

(continued)

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Graduate Research Assistants: Ph.D.: P. Cheng, V. Jonnalagadda, Wei Tang, & T.C. Wey

M.S.: H. Chuang, D. O'Neil, J. Rogers, A. Sareen, & P. Sriram

CONTRIBUTED TO PROJECT BUT WERE NOT SUPPORTED:

Faculty: J.J. Harper

M.S. Students: Cheryl Breevoort, P. Georges, W. Hatch, E. Horowitz, J. Humphries, M. Obal, D. Prichard, D. Stuber, D. Taylor, & R. Tipton

Ph.D. Students: M. Hashemi-Kia & Y. Yillikci

DEGREES AWARDED:

NAME	DEGREE - DATE	PRESENT AFFILIATION
T. Boyd	M.S. - Sept. 1983	U. S. Air Force
C. Boyette	M.S. - Dec. 1983	Ph.D. Program, Ga. Tech
C. Breevoort	M.S. - Sept. 1983	Lockheed Georgia Co.
K. Engelhardt	M.S. - Sept. 1983	Ph.D. Program, Ga. Tech
V. Jonnalagadda	M.S. - Sept. 1983	Ph.D. Program, Ga. Tech
T. Parham	M.S. - Sept. 1983	Bell Helicopter Textron
G. Power	M.S. - Sept. 1983	Ph.D. Program, Ga. Tech
J. Rogers	M.S. - Sept. 1983	General Dynamics
S. Sparks	M.S. - Sept. 1983	United Technologies Research Center
T. Thompson	M.S. - Sept. 1983	Ph.D. Program, Ga. Tech
T. Wey	Ph.D. - Dec. 1983	-

RESEARCH TASKS

I. Aerodynamics

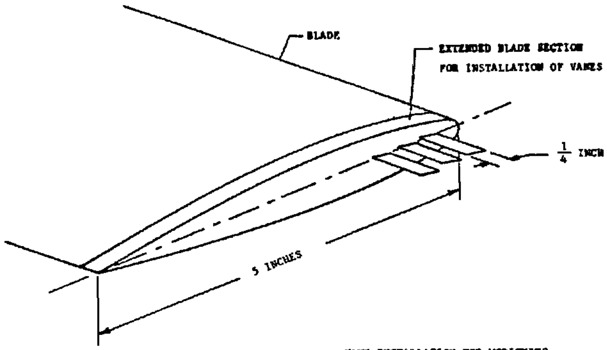
Task 1. Experimental Studies for Tip Vortex Core Modelling
R. B. Gray, N. Komerath, C. Boyette, & T. Thompson

The objective is to develop a capability for using a two-component laser doppler velocimeter to measure the flow field near the tip and in the wake of a hovering model helicopter rotor. The resulting data will be used to guide the development of a tip vortex core model for use in free wake analyses to predict blade loadings. The status of the velocimeter and data acquisition system is described in the Facilities/Equipment Section of this report. Testing is not scheduled to begin until late in the next reporting period.

Task 2. Modification of Blade Tip Loading to Improve Hovering Figure of Merit
R. B. Gray, C. Boyette, W. Hatch, & T. Thompson

Measured pressure distributions on the tip of a hovering model rotor blade show a low pressure region which is associated with the roll-up and rearward sweep of the tip vortex over the trailing 50% of the blade upper surface. This low pressure region near the trailing edge contributes significantly to the section pressure drag and hence to the rotor power required. On the other hand, the region does result in higher thrust loadings near the tip which is advantageous. A study of the measured pressure distributions shows that if, for example, the low pressure region could be eliminated, then the thrust and torque of the model blade would both be reduced (for a blade pitch angle of 11.4°, 1½% decrease in thrust and 7% decrease in torque, approximately) which results in a net increase in the figure of merit (approximately 5% in the case cited). The objective, then, is to explore the possibilities of improving hovering performance by modifying the tip pressure distribution.

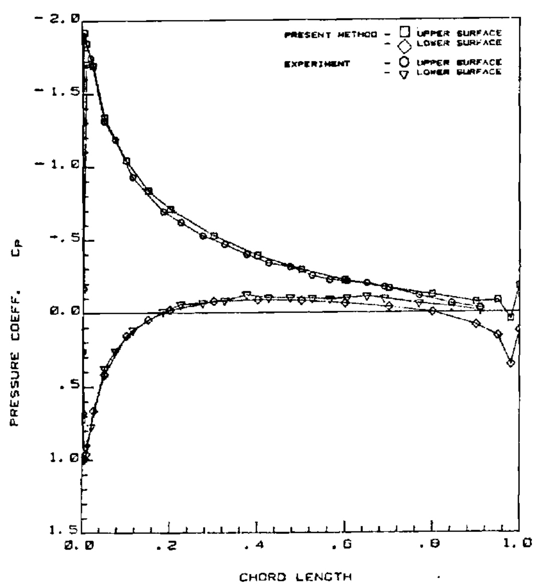
The test configuration selected on the basis of some flow visualization studies in the literature has three small winglets mounted near the leading edge of the blade on the square, flat tip surface as shown below. Each winglet chord is 5% of the blade chord and span is varied over the range of 0 - 4% of blade radius by changing sets. Winglet incidence relative to blade chord line can be manually varied. Current data show that the longer span winglets generally degrade performance. However, data for winglets having a span of 1.8% of blade radius show a thrust increase of 6.6% with little change in torque. This is a surprising result and further validation is required since the initial reaction to this is that the measurements are in error.



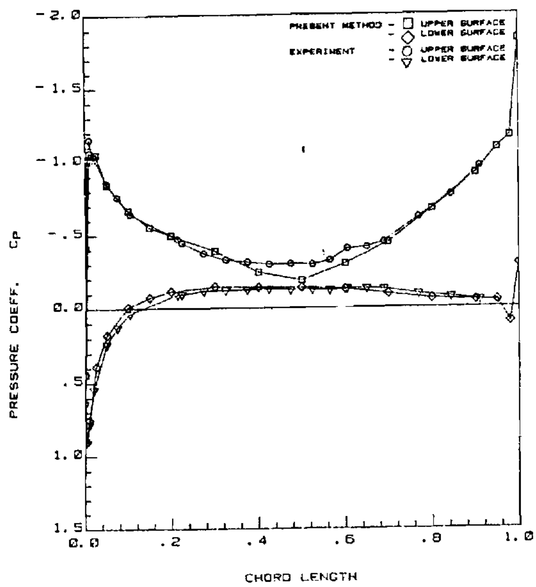
VANE INSTALLATION FOR MODIFYING
BLADE TIP PRESSURE DISTRIBUTION

Task 3. A Procedure for Computing Rotor-Blade/Tip-Vortex Interactions
R. B. Gray, S. G. Lekoudis, B. E. Wake, & T. C. Wey

An iterative, lifting surface, vortex panel method has been developed for computing the surface pressure distribution in hover on a thick rotor blade with a half-body of revolution tip. The basic viewpoint underlying the development of this method was to assess the viability of an inviscid, incompressible flow model with the implied classical theorems while employing empiricisms which appear to be reasonably well accepted. The investigation was one of numerical experimentation and two examples of the results in comparison with measured data are shown below. A final report of this phase of this task is available (Dr. Wey's PhD dissertation).



CASE I. BLADE PITCH ANGLE OF 11.4°, 94.0% RADIUS



CASE I. BLADE PITCH ANGLE OF 11.4°, 99.5% RADIUS

The long term objectives of this task include the capability of obtaining solutions for the blade flow field without empirical input. The following paragraphs describe these continuing efforts.

In the last progress report, the development of a Euler code was described. The code was used to predict the transonic flow around wings of arbitrary shape. Since then the code has been converted into a blade code. Calculations for a hovering rotor are being done. The numerical scheme is the same as explained in the last progress report.

The hover calculations are being done as follows. The inner boundary of the computational domain is at a prescribed span station, currently at 60% span. Therefore only the outboard region of the blade is in the computational domain. The grid, and the blade, rotates at a prescribed angular velocity. The tip Mach number is kept subsonic. The freestream velocity is zero. The advantage of the generality of the scheme is that to go from hover to forward flight, the only change required is the prescription of a freestream velocity together with the rotation speed of the grid.

Due to current storage limitations on the CYBER 855, the code will be transferred to either the IBM 4341 of the Office of Computing Services or on the IBM 4341 being set up for CAD/CAM applications. Mr. Brian Wake, a new graduate fellow is already thoroughly familiar with the numerics and the code.

A new copy of the user's manual for VSAERO-B and -H has been received from NASA Langley. The code, developed by Analytical Methods, solves the subsonic flow around oscillating wings. The code will be released by Langley, and although not directly usable for blade calculations, can aid in the effort of understanding unsteady loads in three dimensions.

Task 4. Studies of Unsteady Rotor Aerodynamics

J. C. Wu, N. L. Sankar, G. D. Power, & W. Tang

Work continued on the development of an unsteady, two-dimensional compressible, viscous flow code capable of analyzing the dynamic stall phenomenon. At present this code gives reliable results for a variety of laminar flow conditions: $5000 < Re < 280000$, $0.2 < M < 0.4$, $0.1 <$ Reduced Frequency $\frac{\omega c}{U_\infty} < 1.0$.

This code has also been checked out for steady inviscid, rotational flows past arbitrary airfoils, including high subsonic and transonic flows.

During the above reporting period, a two-layer eddy viscosity model was incorporated into this code. For a nonlifting case tested (NACA 0012 Airfoil, $M_\infty = 0.5$, $Re = 10^6$) this code gave excellent pressure distribution over the airfoil, but underpredicted the surface skin friction. For lifting cases, the lift coefficient C_L is also somewhat underpredicted. This underprediction seems to be a result of the C-grid currently used. Work is being performed to improve the lift prediction and skin friction prediction capabilities.

A three-dimensional Euler program is being checked out systematically by computing steady transonic flow past practical wing-alone configurations.

A zonal procedure for computing viscous flows is being refined. This procedure permits the confinement of the computation field to the viscous part of an incompressible flowfield. It further permits the various viscous components of the flow to be computed separately. This procedure is ideally-suited for computing high Reynolds number flows containing massive separated regions. The difficulties presented by the co-existence of the various length scales associated with the various viscous and inviscid flow components present in such flows are removed by the zonal approach through the aforesaid distinguishing abilities of this approach. Concurrent with the refinement of the zonal approach, a viscous theory of aerodynamics is utilized to study several problems. This theory permits the contributions of various flow elements to the aerodynamic load to be identified and evaluated individually. Efforts are directed towards improving the understanding of the physical processes involved in the complex rotor aerodynamics problem through coordinate theoretical and computational studies.

Task 5. Studies of the Airframe Flow Field in Forward Flight
J. E. Hubbartt, H. M. McMahon, K. D. Engelhardt,
E. V. Horowitz, D. R. O'Neil, & J. W. Rogers

Tests have shown that the rotor drive system functions properly over the full speed range. Some changes have been made in the system to improve rigidity and it is now mounted in position above the wind tunnel test section. The rotor blade and the hub that attaches the rotor to the drive shaft have been fabricated. After the rotor blade and the drive shaft have been balanced separately, the complete rotor system will be installed in the wind tunnel for shakedown tests.

The fuselage model, which will not be attached to the rotor but, instead, mounts separately to the wind tunnel balance, has been under fabrication that has been proceeding in parallel with the development of the rotor system. The machine work on this model is about 40 percent complete.

Experience is being acquired in the use of the new computer-based data acquisition system by assisting in the taking of data necessary for the calibration of the renovated test section of the Nine-Foot Wind Tunnel. Knowledge gained from these tests will be used in developing the techniques and data acquisition programs for the investigation of the airframe flow field in forward flight.

The overall objective of this research is the validation of a practical theory for predicting the interactions between the rotor and airframe flow fields. The first step in this process is an assessment of existing analyses. Therefore, copies of existing computer codes are being acquired and efforts are underway to adapt them to our computers and to become proficient in their usage. To date, one code has been obtained from the U.S. Army Applied Technology Lab at Fort Eustis and a second code has been obtained from the U.S. Army Structures Lab at Langley Research Center. A third code has been requested from NASA Ames Research Center. The first of these codes is for a uniform freestream flowing around a 3-dimensional body. It is of interest here since it contains a practical boundary layer solution and a panel method which may be incorporated in other codes. The second program is the Freeman code, which mates the vortex-tube rotor wake model to the Douglas-Neumann program for 3-dimensional potential flow about arbitrary bodies. This is of interest since it represents the simplest approach to this complex problem and provides a simple basis for expansion. As yet, these two programs have not been run successfully on the Georgia Tech computers because of problems encountered due to computer differences, program errors, and a lack of adequate documentation. The third code, currently being acquired from NASA, is for fully coupled rotor/airframe aerodynamics and uses a low order panel method for the body and a blade element model for the rotor. This advanced method was developed by Analytical Methods, Inc. under NASA contract and has just become available for distribution.

II. Structures

Task 1. Structural Dynamic System Identification

S. V. Hanagud, J. I. Craig, M. Meyyappa, C. Breevoort, Y. Cheng, C. Grimmell, M. Obal, & D. Stuber

A second generation structural dynamic physical model has been fabricated. The design of the model is based on the drawings and information received from the U. S. Army Laboratories at Fort Eustis, Virginia. The fabricated model has been tested to obtain specific mode shapes and natural frequencies. The test output is at present being compared with the analytical finite element model that has been developed at Georgia Tech.

A technique has been developed to design structural dynamics physical models. This design procedure translates the quantitative structural dynamic information, such as finite element models, of a given full scale structure (or a major component) to the physical model. In the past, the structural dynamic physical scale models have been designed by near replication of the full scale structure or by distributing the lumped mass qualitatively. The developed design procedure closely duplicates selected natural frequencies and mode shapes of the full scale structure and thus provides approximate simulation of the real time dynamic response. Additional constraints are being considered. A paper in this field entitled "Structural Dynamic Physical Models of Helicopters by Identification Technique" has been presented at the Ninth European Rotor Craft Forum.

A technique for identifying the structural dynamic physical models that involve nonproportional damping has been developed. A paper in this field will be presented at the 25th Structures, Structural Dynamics and Materials Conference sponsored by AHS, AIAA, ASME and ASCE. The meeting will be held during May 1984. The technique for identifying nonlinear systems with single degree of freedom is being extended for systems with multiple degrees of freedom.

Task 2. Crashworthy Characteristics of Composite Rotorcraft Structures
S. V. Hanagud, S. Chandrashekara, S. Sarkar, & P. Sriram

Static postbuckling tests on selected composite sandwich specimens are in progress. These composite sandwich specimens have graphite-epoxy composite faceplates and a hybrid crush-zone core. The dynamic test facility has been designed. At present, the dynamic test facility is being fabricated. The test facility consists of two parts and these will be built in two stages. The first part consists of dropping a selected weight onto a test specimen. This arrangement will be used to conduct dynamic bucking tests on crashworthy structures. The same facility will also be used to evaluate the transient dynamic response of selected specimens. The second facility will allow selected structural components or these scale models to be dropped on selected targets from selected heights. This facility will be used to evaluate structures in crash situations and provide future design criteria.

Another basic research program in this subtask is to develop numerical techniques and computer programs to obtain the transient dynamic response of energy absorbing structural components. This will assist a structural designer to: (a) select appropriate materials and their dimensions, and (b) optimize the design. As a part of this program, constitutive equations are being developed for the energy absorbing materials. These constitutive equations will describe the behavior of the materials under conditions of finite deformations. Some simple constitutive relationships have been incorporated in computer programs.

III. Aeroelasticity

Task 1. Helicopter Vibration Suppression Techniques
G.A. Pierce, V. Anand, J. Jonnalagadda, T. Parham, A. Sareen, D. Taylor, R. Tipton

This program is intended to develop and validate a comprehensive vibratory loads analysis for the design evaluation of vibration suppression techniques. The loads analysis will be applicable to nonuniform multi-bladed systems with teetering, articulated, hingeless or bearingless hub constraints. Special emphasis will be placed on blade structural dynamics, hub and mast dynamics, impedance of the rotor/airframe interface, and unsteady blade aerodynamics. The vibration suppression techniques to be considered will include higher harmonic pitch control, blade-mounted absorbers, hub-mounted absorbers, and aeroelastic tailoring.

The vibratory loads analysis as originally formulated is a discrete frequency harmonic analysis which yields a complete solution to the governing differential equations of a multi-bladed rotor system. To apply this technique to a system which incorporates higher harmonic pitch control has necessitated a radical modification to the governing blade equations. The modification entails the inclusion of prescribed integral harmonic signals in the collective and cyclic pitch coefficients of the nonrotating control system.

Subsequent resolution into the rotating blade system naturally requires a multi-frequency harmonic analysis. It may be noted that the multi-frequency solution is compatible with a more accurate representation of the aeroelastic coupling which had previously been compromised by neglecting the interharmonic terms. When the multi-harmonic analysis has been completed it will then be a relatively straight forward procedure to incorporate a discrete harmonic feedback loop in the simulation with an appropriate controller for evaluation of higher harmonic pitch control schemes.

In addition to these efforts directed toward the analytical development there has been a paralled analytical program in support of the validation objectives. More specifically a capability is being developed to analyze prospective aeroelastic rotor models from the standpoint of modal characteristics and flutter stability. The integrating matrix technique has been programmed for the determination of coupled rotating normal modes of vibration in a vacuum. Two stability analyses have been made available and checked out for future applications. The first is the FLAIR code for ground and air (hover) resonance studies of bearingless rotor configurations. This code and supporting documentation were obtained from Dr. Dewey Hodges of the Aeromechanics Laboratory of AVSCOM. The second stability code has been programmed in-house from the development presented in NASA TN D-8192 by Drs. Hodges and Ormiston for hingeless rotor configurations in hover.

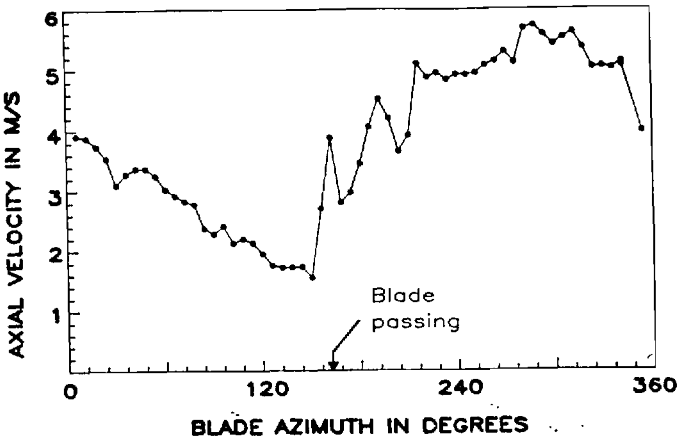
FACILITIES/EQUIPMENT

I. Laser Doppler Velocimeter Data Acquisition System

R. B. Gray, J. E. Hubbartt, H. M. McMahon, & N. M. Komerath

Modifications to the data processing hardware were completed to enable synchronization of the LDV data with the rotor azimuth in the nine-foot static thrust facility. FORTRAN software for performing rotor-synchronized averaging was developed and incorporated into the data processing system. Tests were performed with the single-component LDV system to determine the velocity along the axial direction in the rotor wake. Plots similar to the one shown below were obtained, showing measured velocity as a function of rotor azimuth at six-degree intervals with the rotor spinning at 1200 rpm. Each point in the plot is an average of between 100 and 600 data values, obtained over several revolutions of the rotor. The sharp rise in velocity was found to correspond to the time at which the blade passed the measuring point. The major features in the plots were repeatable between runs. Seeding using atomized water was found to yield data rates up to 3000 per second, but the problems of flow-field interference due to the atomizing stream and of particle lag in vortex regions remain to be solved. These problems cause considerable uncertainty in the velocity data. A test section window of 1/8-inch Plexiglass was found to perform satisfactorily in transmitting and receiving laser light.

The second component of the LDV system was received in late October and is in the final stages of alignment and testing. Problems were encountered in getting the four beams to intersect at a common point at a focal length of five feet using the optical traverse system, but these are expected to be resolved shortly in cooperation with the manufacturers.



Single-component LDV data showing the variation of axial velocity measured in the rotor wake with the rotor blade azimuth.

II. Nine-Foot Static Thrust Facility
R. B. Gray

The facility was designed to provide a laboratory-controlled environment for testing model helicopters up to 4½ feet in diameter in hovering flight. The LDV system described above will have its first use in this facility. The updating of this facility has been delayed to permit some testing to continue.

III. Structural Dynamic System Identification Facility
S. V. Hanagud & J. I. Craig

This is the first year for major development of this facility. Approximately $6,400 was allocated during the first year to acquire 6 accelerometers and two load cells with signal conditioning gear but this was deferred until the second (present) year. The major emphasis during the present year is to acquire a multichannel time series and structural dynamic analyzer for the laboratory. Work to date has involved a detailed survey of currently available equipment for this purpose. After considerable evaluation, it has been decided that the originally proposed equipment has been outdated by the introduction of several new systems that offer equal or better levels of performance at the same or lower costs. The decision has been made not to acquire the HP5451C system, but rather to instead purchase the new GenRad 2515 Computer-Aided Test system (structural dynamics analyzer) along with the GE CAE International (SDRC) MODAL PLUS analysis software. RFQ's have been issued and the equipment is expected to be on the campus before the end of the Winter academic quarter. This system will allow acquisition of data from one to eight channels (expandable to 16) and the analysis software will run either on the internal LSI 11/23 microcomputer or else on an external PDP or VAX system. In addition to the above instrumentation, essential test fixtures and associated hardware for the laboratory have been fabricated in the shop. Much of this is currently in use with the model test program (using an older analyzer borrowed from another laboratory in the School).

IV. Transient Dynamic Stress Analysis Facility
S. V. Hanagud & J. I. Craig

This is the first year for development of this laboratory and the major effort to date has been spent in designing a dynamic loading facility and in acquiring the basic transient waveform recording equipment. Several different schemes for developing a dynamic loading fixture were evaluated. The approach adopted involves development of a straightforward drop test fixture for producing dynamic compressive loading of various test articles. The system is built around a vertical 3-meter by 150-mm-diameter steel tube that guides the drop weight (20 kg maximum). The guide tube will be supported in position within an existing inactive structural test rig that provides suitable support and access both at the top and at the bottom. This facility is located on a thick structural floor system that will provide an excellent base for the test fixture. A tubular guide tube was selected in order to allow future augmentation of the facility capacity (impact energy, dynamic loads) by adding either pneumatic or mechanical (spring) boost to the drop weight. Appropriate mountings for sensors, etc., have been provided. To date, the design has been completed and preliminary shop drawings have been made. Much of the basic material (guide tube) has been ordered and arrangements for machining work have been completed. A number of different waveform recorders have been evaluated and a request for purchase has been submitted. Delivery of a basic two channel unit is expected during the winter quarter.

V. Nine-Foot Wind Tunnel Facility
J. J. Harper, J. E. Hubbartt, H. M. McMahon, & S. S. Kleinhaus

The original nine-foot low speed wind tunnel was to be converted to a 7x9-foot forward flight facility. The design and installation of fairings, floor and ceiling have been completed. Test section flow calibration to include speed control, flow angularity, dynamic pressure variation, static pressure gradient and turbulence factor is in progress. Preparations for a total force balance calibration are in progress.

A new steel test section platform to carry the weight of the laser velocimeter has been installed. The design and installation of removable steel safety shields around the test section and over the console viewing area is complete.

The control room has been partitioned off and air conditioned and new motor-balance consoles installed. The computer and peripheral equipment dedicated to the force balance are in place. Other instrumentation for additional data acquisition is on order.

VI. Sixteen-Foot Rotor-Test Facility
G. A. Pierce, S. S. Kleinhaus, & R. B. Gray

This new test facility will accommodate model rotor systems of eight-foot diameter. Currently planned test programs include dynamically excited aeroelastic models for vibratory loads studies and rigid models for both steady and unsteady aerodynamic measurements.

After steel was erected in June, the structure of the facility has been completed by applying honeycomb panels to both inlet and outlet areas as well as painting of all structural members. The motor platform was completed along with the interior of the control room. The rotor mast was machined and finished by a subcontractor and all of its internal and external parts were assembled and the entire unit balanced. Installation is planned for late January. Simultaneously with work on the facility, conceptual and preliminary design of the first research rotor was undertaken. It will be a bearingless, 4-bladed, Froude-scaled rotor with a tip diameter of 96" and operating at 700 RPM. Investigations into manufacturing techniques for in-house fabrication of the rotor components were initiated.

NEW COURSE DEVELOPMENT

The development of the following courses has begun or is complete. The development of the remaining new courses has been scheduled for a later reporting period.

I. Vibration Measurement and Analysis
J. I. Craig

The new course (AE6132) on structural dynamics measurement and analysis has been developed and will be taught during the Spring 1984 quarter. Preregistration figures are not available at this time but it is anticipated that the enrollment will be 15 to 20. The course builds on the preceding formal coursework in analytical methods for structural dynamics (two quarters) and introduces methods for structural vibration excitation and measurement. Considerable time will be spent dealing with modern methods for time series analysis and their application to the problems of vibration measurement and dynamic response analysis. Basic techniques for modal analysis will be introduced, but more detailed study of these methods will be included in the course on System Identification (AE6133).

II. System Identification
S. V. Hanagud & J. I. Craig

The course outline, preparation of some lecture notes, design of laboratory tests, and certain computer programs have been completed. It is planned to offer the course during the Summer or Fall quarters of 1984.

III. Finite Deformation of Aircraft Structures
S. V. Hanagud

A course outline has been prepared and work on arranging the lecture material is continuing. The completion of this course is scheduled for a later period.

IV. Computational Aerodynamics
S. G. Lekoudis

This is an introductory course. The course outline has been prepared and the lecture notes are complete. It will be offered during a later period.

V. Viscous Flow III
S. G. Lekoudis

This course was taught for the first time during the Summer of 1983. The class had seven graduate students. The topics covered were basically the models used in turbulent flow: algebraic models, differential equation models, stress transport models, and large eddy simulation. The last part of the course was devoted to the findings of the 1981-82 Stanford Conference on Complex Turbulent Flows.

VI. Numerical Fluid Dynamics III
J. C. Wu

This course is designed to acquaint the students with the state-of-art engineering applications of computational aerodynamics with special emphasis on rotary wing aircraft applications. It was developed and offered in the Fall of 1983. Eleven graduate students were enrolled.

UPDATED COURSES

The updating of courses has been completed and their description has appeared in previous progress reports.

VISITS/COMMUNICATIONS

I. R. B. Gray

University of Maryland, September 26, 1983

The meeting was attended by Dr. R. G. Loewy of RPI and myself and was hosted by Professor Al Gessow and the faculty of the A. E. Department and COE in Rotary Wing Aircraft Technology. Discussions centered on areas of mutual interest in research programs and facilities, educational programs, and recruitment of graduate students. A tour of their facilities was given.

Rensselaer Polytechnic Institute, October 3, 1983

The meeting was attended by Professor Al Gessow of the University of Maryland and myself and was hosted by Professor Loewy and the faculty of the COE in Rotary Wing Aircraft Technology. Tours of the laboratories and presentations of the research tasks were given. Discussion of the mutual areas of interest were continued.

Kaman Aerospace Corporation, Bloomfield, CT, October 4, 1983

My visit was arranged by Dr. Andy Lemnios, Director of Research and Technology. I described our Center's activities and was given an overview of the Corporation and the research activities in Bloomfield. The possibilities of interactions were discussed.

United Technologies Research Center, October 4, 1983

My visit was arranged by Dr. Jack Landgrebe, Manager of Aeromechanics Research. About an hour was spent discussing our Center's activities with 8-10 of their professional staff and the need to develop interactions. A tour of some of their facilities was given and areas of mutual research interest were discussed.

I. R. B. Gray (continued)

Sikorsky Aircraft, October 5, 1983

My visit was arranged by Dr. Dave Jenney, Chief of Technical Engineering. There was a full day's program of tours and discussions with individual groups. There are areas of mutual interest and opportunities for cooperation for all of our research tasks.

University of Maryland, October 14, 1983

Dr. Jewel B. Barlow, Director, Glenn L. Martin Wind Tunnel, visited our Center for tours of our facilities and discussions with Gray, Hanagud, Hubbartt, Kleinhaus, Komerath, McMahon, and Pierce.

Hughes Helicopter, Inc., November 7, 1983

Dr. Dave Banerjee, Chief of Aeromechanics Research and Development, visited our Center and discussed the activities at Hughes with our undergraduate and graduate students.

Rensselaer Polytechnic Institute, November16, 1983

Professor Robert G. Loewy visited our Center for a tour of our facilities and discussions on graduate programs, research tasks, and areas of mutual interest to the Centers. Professor Al Gessow was unable to attend at the last moment.

December 1983

Letters and telephone calls were initiated with several companies inquiring about the possibility of obtaining helicopter components for use in several of the research tasks and of obtaining advice for constructing model blades from composite materials. A tape of HESCOMP, the Helicopter Sizing and Performance Computer Program was requested from the Boeing Vertol Company.

II. S. V. Hanagud

Ninth European Rotorcraft Forum, Stresa, Italy, Sept. 13-15, 1983

A paper was presented at the Forum. Discussions on the generic topic of structural dynamics in the design of helicopters were had with technical personnel from Augusta and Aerospatialle. Discussions also occurred with technical staff of DFVLR on the design of their dynamic drop-test facility.

Agusta S.P.A., September 14, 1983

A visit was made and discussions continued.

DFVLR, Stuttgart, September 18, 1983

A brief visit was made and discussions continued.

Army Aviation Safety Center, Fort Rucker, November 28, 1983

A visit was made to this Center to discuss their helicopter crash investigation program with Dr. James Hicks. The need for basic research that would lead to crashworthy rotorcraft structures was explored.

III. J. E. Hubbartt

USARTL, Fort Eustis, VA, July and August 1983

Exchanged letters and telephone calls with Mr. Don Van and Mr. Louis Bartek leading to the acquisition of a computer code in late August 1983.

USARTL and NASA, Langley Field, VA, July-October 1983

Exchanged letters and telephone calls with Mr. John Berry, Mr. Carl Freeman, and Mr. James Thomas leading to the acquisition of a computer code in October 1983.

III. J. E. Hubbartt (continued)

USARTL, Langley Field, VA, July 18 and 20, 1983

Telephone calls were made to Mr. John Berry and Mr. Art Phelps to inquire about information on rotor hub balances. They were not able to provide any useful information on hub balances.

NASA, Moffett Field, CA, November and December 1983

Telephone calls to Mr. Charles Smith inquiring about the possibility of obtaining the AMI computer code. The codes were promised in early 1984 when the documentation reports become available.

IV. J. E. Hubbartt, H. M. McMahon, & N. Komerath

USARTL and NASA, Langley Field, VA, November 7, 1983

Messrs. John Berry, Henry Kelley, and Joe Elliott and Drs. Hamouda, Bill Hunter, J. F. Meyers, and Jim Schiemann were visited to discuss research and problems of mutual interest concerning helicopter flow fields and the use of the LDV. Valuable personal contacts and information were obtained from this visit.

V. S. S. Kleinhaus

IRD, Columbus, OH, July 19-20, 1983

A short course on the field balancing of rotating machinery was attended.

Zonic Laboratories, Cincinnati, OH, July 21, 1983

The visit was made to discuss design incorporation of their excitation system into the rotor-test facility.

V. S. S. Kleinhaus (continued)

Deep Hole Specialists, Cleveland, OH, July 22, 1983

This facility was visited to make a quality control check on the drive shaft being manufactured for the rotor-test facility.

Grumman Aerospace Corporation, Milledgeville, GA, December 6, 1983

This visit centered on discussions on composite manufacturing techniques with the objective of building up a capability at Georgia Tech for constructing model blades of composite materials.

University of the Witwatersrand, South Africa, December 7, 1983

A letter was received from Dr. Nurick which inquired about special problems that had been encountered in building our rotor-test facility. Dr. Nurick is working on a similar facility. A short summary was forwarded.

VI. S. G. Lekoudis

USARTL, Langley Research Center, October 25, 1983

A visit was made to Dr. Warren Young to discuss fluid mechanics problems related to helicopter aerodynamics.

VII. G. A. Pierce

USARTL, Ames Research Center, July 13, 1983

An aeroelastic stability code known as FLAIR was requested and subsequently received from Dr. Dewey H. Hodges.

VII. G. A. Pierce (continued)

USARTL, Ames Research Center, July 18, 1983

Dr. Dewey Hodges visited the Center for discussions on dynamics and vibrations with Drs. Craig, Hanagud, Pierce, and Rehfield. He met with Dr. Gray for a tour of the facilities and a briefing on the graduate programs and aerodynamic research.

Hughes Helicopters, Inc., September 7, 1983

A telephone call was made to Mr. Richard Powers to discuss the academic requirements of a scholarship program to be offered Georgia Tech graduate students by Hughes Helicopters.

AVRADCOM, St. Louis, MO, October 10, 1983

Dr. Daniel P. Schrage, Director of Advanced Systems visited with members of the faculty and presented a seminar entitled: "Design Philosophy - Fixed versus Rotary Wing Aircraft".

USARTL, Ames Research Center, October 11, 1983

Mr. William G. Bousman of the Aeromechanics Laboratory visited with members of the faculty and presented a seminar entitled: "Experiments in Rotorcraft Stability at the U.S.A. Aeromechanics Laboratory".

December 2, 1983

A news release which discussed our analytical and experimental efforts in vibration suppression was prepared for the Georgia Tech News Bureau. The release was submitted to Popular Mechanics Magazine and the Atlanta newspapers.

VIII. J. C. Wu & N. L. Sankar

USARTL, Ames Research Center, December 19, 1983

The visit was arranged to discuss various technical topics in unsteady aerodynamics with Drs. Chee Tung, Frank Caradona, and Ken McAlister of USARTL and Dr. Sanford Davis of NASA. A seminar was presented on recent theoretical and computational research in unsteady aerodynamics at Georgia Tech.

ADVISORY BOARD

The First Advisory Board Meeting was held on August 25, 1983. Those members attending were: Dr. Daniel P. Schrage, Director of Advanced Systems, AVRADCOM; Mr. Richard Long, Director, Structures Laboratory, USARTL-Langley; Mr. Robert R. Lynn, Sr. V. P. of Research and Engineering, Bell Helicopter Textron; Mr. Kenneth L. Grina, V. P. of Engineering, Boeing Vertol Company; Dr. Andrew Z. Lemnios, Director of Research and Technology, Kaman Aerospace Corporation; and Dr. David S. Jenney, Chief of Technical Engineering, Sikorsky Aircraft. Mr. William R. Ellis, V. P. for Marketing, Hughes Helicopters, Inc. was unavailable and Hughes was represented by Mr. James H. Brown, Jr., Manager, R & D Marketing. Dr. Irv Statler, Director, Aeromechanics Laboratory, USARTL-Ames and Mr. John F. Ward, Manager, Rotorcraft Technology Office, NASA, were unable to attend at the last moment.

The Board members were briefed on the academic and research programs and the experimental facilities. The discussion period that followed dealt with the needs of government/industry and how the Center can help fulfill the needs, the needs of the Center and how government/industry can help, establishment of interactions both ways, and other ways government/industry can assist in the development of the Center. The faculty felt that the meeting was extremely worthwhile.

HELICOPTER DESIGN PROFESSOR

Dr. Daniel P. Schrage, Director of Advanced Systems, AVRADCOM, has accepted our offer to be the Center's Helicopter Design Professor. Dr. Schrage will arrive on campus on January 4, 1984. His primary responsibility will be the development and teaching of the graduate design courses in the Spring and Summer quarters of 1984.

Eleven graduate and undergraduate students have indicated an interest in participating in the AHS/Boeing-Vertol Rotary Wing Design Competition. Dr. Schrage has agreed to organize these students into teams and to be their faculty advisor in this activity.

STRUCTURAL DYNAMIC PHYSICAL MODELS OF HELICOPTERS BY IDENTIFICATION TECHNIQUE

S. V. HANAGUD, M. MEYYAPPA and J. I. CRAIG

School of Aerospace Engineering

Georgia Institute of Technology

Atlanta, Georgia, U.S.A.

ABSTRACT

The techniques and procedures for the design of structural dynamic physical models have been discussed in this paper. The design procedures for these scale models are based on the actual quantitative structural dynamic information available on a given full scale structure such as the helicopter or a major component of the helicopter. The available structural dynamic information can be in the form of a finite element model or the experimental data on the full scale structure. In the past, the structural dynamic physical scale models have been designed and fabricated either by near replication of the full scale structure or by the use of the experience factor and lumped mass arrangements.

The design objective in this paper is to simulate selected natural frequencies and mode shapes of the full scale structure. The procedure also includes some possible constraints such as the preservation of aerodynamic surfaces and minimum thicknesses. Whenever possible the design can be restricted to utilize commercially available hardware.

The design procedure has been developed by using structural dynamic identification techniques and optimization procedures. The developed procedure has been used to illustrate the design of a half-scale model of the tail boom of a selected helicopter. The constraint on the aerodynamic surface has been removed in the example design.

HELICOPTER VIBRATION SUPPRESSION USING SIMPLE PENDULUM ABSORBERS ON THE ROTOR BLADE

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Research Engineer

Vigyan Research Associates, Inc.
Hampton, Virginia

and

G. Alvin Pierce
Professor

Georgia Institute of Technology
School of Aerospace Engineering
Atlanta, Georgia

Abstract

A design analysis for the installation of simple pendulums on the blades of a helicopter rotor to suppress the root reactions is presented. This analysis consists of a frequency response study for a hingeless rotor blade excited by a harmonic variation of spanwise airload distribution, during forward flight, as well as a concentrated load at the tip. A single blade with hingeless hub restraint undergoing coupled flapwise bending, chordwise bending, and torsional vibrations is considered with both uniform and nonuniform properties. Simple flap and lead-lag pendulums are treated individually. On the basis of a rational ordering scheme the general nonlinear equations of motion are linearized. A quasi-steady aerodynamic representation is utilized in the formation of the airloads. The solution of the system equations is based on their representation as a transfer matrix. The results include the effect of pendulum tuning on the minimization of hub reactions. The pendulum mass effectiveness is also investigated. The results for the concentrated load and the distributed airloads are compared.

E-16-684

PROGRESS REPORT

1. ARO PROPOSAL NUMBER: 19364-E

2 PERIOD COVERED BY REPORT: 1 JANUARY - 30 JUNE 1984

3. TITLE OF PROPOSAL: A CENTER OF EXCELLENCE IN ROTARY WING AIRCRAFT TECHNOLOGY

4. CONTRACT OR GRANT NUMBER: DAAG29-82-K-0094

5. NAME OF INSTITUTION: GEORGIA INSTITUTE OF TECHNOLOGY SCHOOL OF AEROSPACE ENGINEERING

6. AUTHOR(S) OF REPORT: R.B. Gray, J.I. Craig, S.V. Hanagud, J.J. Harper, J.E. Hubbartt, S.S. Kleinhaus, N.M. Komerath, S.G. Lekoudis, H.M. McMahon, S.A. Meyer, G.A. Pierce, N.L. Sankar, D.P. Schrage & J.C. Wu

7. LIST OF MANUSCRIPTS SUBMITTED OR PUBLISHED UNDER ARO SPONSORSHIP DURING THIS PERIOD, INCLUDING JOURNAL REFERENCES:

PAPERS:

"Graduate Rotorcraft Programs at Georgia Tech"
R.B. Gray
ASEE Annual Conference, Salt Lake City, UT, June 24-26, 1984

"A Numerical Analysis for Blade Tip Loadings on a Thick Bladed Hovering Helicopter Rotor"
T.C. Wey
PhD Dissertation supervised by R.B. Gray. Copies sent to other COE's, USARTL's, helicopter companies and others.

"Identification of Structural Dynamic Systems with Nonproportional Damping"
S.V. Hanagud, M. Meyyappa, P. Cheng, & J.I. Craig
Presented at AIAA/ASME/ASCE/AHS 25th Structures, Structural Dynamics and Materials Conference, Palm Springs, CA, May 14-16, 1984

"Method of Multiple Scales and Identification of Nonlinear Structural Dynamics Systems"
S.V. Hanagud, M. Meyyappa, & J.I. Craig
Revised for publication in AIAA Journal

"A Two-Step Version of Strang-Gottlieb Techniques for Deformable Lagrangian Meshes"
S.V. Hanagud & H.P. Chen
Presented at the US Army Conference on Numerical Methods, Renssalear Polytechnic Institute, Troy, NY.

8. SCIENTIFIC PERSONNEL SUPPORTED BY THIS PROJECT AND DEGREES AWARDED DURING THIS REPORTING PERIOD:

Faculty: J.I. Craig, A.L. Ducoffe, R.B. Gray, S.V. Hanagud, J.E. Hubbartt, S.G. Lekoudis, H.M. McMahon, G.A. Pierce, D.P. Schrage, & J.C. Wu

Research Engineers: S. Kleinhaus, N. Komerath, R. Latham, & N.L. Sankar

Research Associates: J. Caudell & H. Meyer

Post Doctors: V. Anand, A. Chandrashekara, H.P. Chen, M. Meyyappa, & C. Wang

Fellows: Ph.D.: Cynthia Boyette, Kathryn Dunlop Engelhardt, Gregory D. Power, Thomas L. Thompson, & Dana J. Taylor

M.S.: Christopher A. Grimmell & Brian E. Wake

Graduate Research Assistants: Ph.D.: P. Cheng & V. Jonnalagadda

M.S.: H. Chuang, D. O'Neil, A. Sareen, & P Sriram

CONTRIBUTED TO PROJECT BUT WERE NOT SUPPORTED

FACULTY: J.J. Harper

Ph.D. Students: M. Hashemi-Kia & Y. Yillikci

M.S. Students: P. Georges, E. Horowitz, J. Humphries, M. Obal, D. Pritchard, D. Stuber, & R. Tipton

DEGREES AWARDED (Cumulative)

NAME	DEGREE-DATE	PRESENT AFFILIATION
T. Boyd	MS - Sept 1983	US Air Force

C. Boyette	MS - Dec 1983	Hughes Helicopters
C. Brevoort	MS - Sept 1983	Lockheed Georgia
CPT C.N. Cardinal	MS - June 1984	US Army
H.P. Chen	PhD- Dec 1983	Georgia Tech
MAJ M. Clifford	MS - Dec 1982	US Army
J.E. Corban	*BAE- June 1983	Hughes Helicopters, Inc
P.L. Elliot, III	*BAE- June 1983	Boeing Vertol Co.
K. Engelhardt	MS - Sept 1983	Hughes Helicopters, Inc
C. Grimmell	MS - June 1984	General Dynamics
MAJ W.J. Hatch	MS - June 1984	US Army
J.A. Humphries	MS - June 1984	US Air Force
V. Jonnalagada	MS - Sept 1983	PhD Program Georgia Tech
CPT W. McArthur	MS - March 1983	US Army
T. Parham	MS - Sept 1983	Bell Helicopter Textron
G. Power	MS - Sept 1983	United Technologies Research Center
J. Rogers	MS - Sept 1983	General Dynamics
S. Sparks	MS - Sept 1983	United Technologies Research Center
T. Thompson	MS - Sept 1983	PhD Program Georgia Tech
T. Wey	PhD- Dec 1983	------

RESEARCH TASKS

I. Aerodynamics

Task 1. Experimental Studies for Tip Vortex Core Modelling
R.B. Gray, N. Komerath, C. Boyette, & T. Thompson

The objectives of this task are to 1) develop a capability for using a two-component laser doppler velocimeter facility and data acquisition system, 2) to measure the flow field near the tip and in the wake of a hovering model helicopter rotor, 3) and to use the resulting data to guide the development of a tip vortex core model for use in free wake analyses for blade loadings predictions. The longer term objectives are to develop a hovering vortex wake analysis which is not as dependent on empirical parameters for describing the tip vortex geometry and to investigate the extension of the vortex wake analysis to low-speed forward flight.

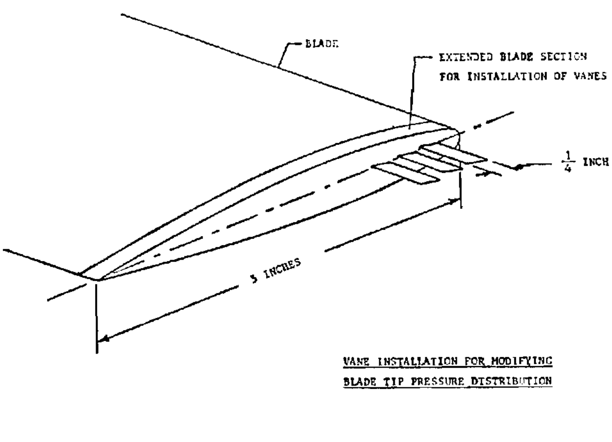
During this reporting period, preliminary wake surveys were made near the wake boundary to obtain variations in the axial and radial velocity components of the flow field with azimuth position of the model blade. Although the data was obtained by averaging over a number of blade revolutions, it clearly showed the passage of the tip vortex for points near the wake boundary, the passage of the blade at points near the plane of revolution, and the passage of the inner vortex sheet at inboard points. The repeatability of the radial component data was very good while that for the axial component was not as good. The lack of good repeatability in the latter case is thought to be due to some rather small unsteadiness in the flow.

The laser velocimeter was moved to the wind tunnel during the month of May to perform some exploratory work for Aerodynamics Task 5. It is scheduled to be returned to the static thrust facility about the middle of July. Efforts will then be directed at improving the seeding system to obtain higher data resolution and increased data rates and continuing the development of the software for acquiring sufficient data during one blade revolution.

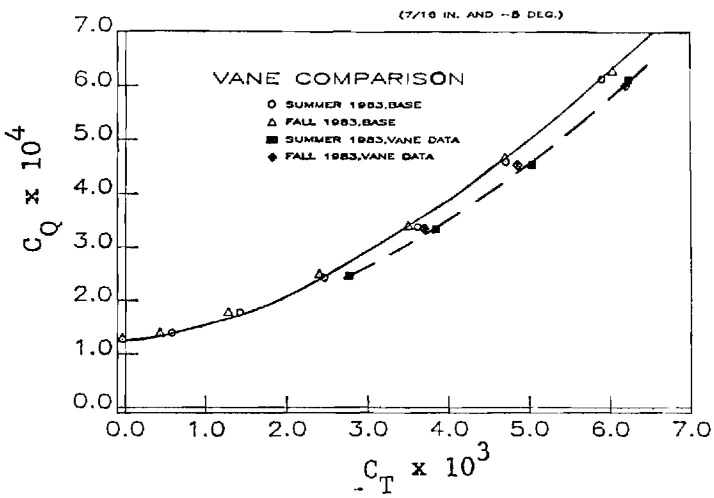
Task 2. Modification of Blade Tip Loading to Improve Hovering Figure of Merit
R.B. Gray, C. Boyette, W. Hatch, & T. Thompson

Measured pressure distributions on the tip of a hovering model rotor blade show a low pressure region which is associated with the roll-up and rearward sweep of the tip vortex over the trailing 50% for the blade upper surface. This low pressure region near the trailing edge contributes significantly to the section pressure drag and hence to the rotor power required. The objective of this task is to explore the possibilities of improving performance by modifying the tip pressure distribution.

The test configuration is shown below. The vane span is varied by changing sets of vanes and the vane incidence with respect to the blade chord line manually. Data for vanes having a span of 1.8% of rotor radius (7/16 inch) and an incidence angle of -5 degrees (nosedown) show a thrust increase of 5.8% with little change in torque. These results from the Summer of 1983 were unexpected so the calibrations and tests were repeated in the Fall of 1983. There was good agreement as shown in the figure below. Tests at an incidence angle angle of -15 degrees showed a thrust increase of 6.6%.



VANE INSTALLATION FOR MODIFYING BLADE TIP PRESSURE DISTRIBUTION



In February of 1984 during a visit to Bell Helicopter Textron, Bell engineers indicated a willingness to provide full scale tests. A quick check-test was made in March and the improvement was not demonstrated. It is intended that some additional investigation will proceed depending on the availability of the test facility and a student assistant. This task will be completed as soon as possible.

Task 3. A Procedure for Computing Rotor Blade/Tip Vortex Interactions
R.B. Gray, S.G. Lekoudis, B.E. Wake, & T.C. Wey

An iterative, lifting surface, vortex panel method has been developed for computing the surface pressure distribution in hover on a thick rotor blade with a half body of revolution tip. The basic viewpoint underlying the development of this method was to assess the viability of an inviscid, incompressible flow model with the implied classical theorems while employing empiricisms which appear to be reasonably well accepted. The investigation was one of numerical experimentation and the results show good agreement with the measured data in some areas but not in others. The work was the PhD research of Dr. T.C. Wey and a paper is being prepared to submit for publication.

The long term objective of this task is the development of a capability of obtaining solutions for the blade pressure distribution without as much empirical input and with the inclusion of viscous and compressibility effects. An Euler code has been converted from a wing code to a rotor code. The three dimensional Euler equations are solved in conservation form for the flow around arbitrarily shaped rotors. The equations are solved using a hybrid implicit-explicit finite-difference scheme. An alternating direction implicit algorithm is used in the airfoil planes and the spanwise derivatives are explicitly evaluated. The solution is based on a time marching procedure. With the hybrid scheme both the speed of explicit schemes and the large time steps of implicit schemes are realized.

The solution is obtained on an algebraically generated C-grid. The code has been used for hover calculations in subsonic flow, in order to compare with existing pressure measurements.

There is currently no wake capability in the code and the generated tip vortex diffuses rather rapidly. This is revealed in the computed pressure distributions because the measured suction peak at the nose is overpredicted. Work is in progress to incorporate a wake into the procedure. The computed flow directions on the surface of the hovering rotor are in qualitative agreement with earlier panel flow studies. The same is true for the spanwise distribution of lift.

This paper has been submitted for presentation to the Aerospace Sciences Meeting in January 1985.

Task 4. Studies of Unsteady Rotor Aerodynamics
J.C. Wu, N.L. Sankar, G.D. Power, & W. Tang

The purpose of this task is the establishment of a comprehensive understanding of the physical mechanisms associated with the generation of unsteady aerodynamic forces acting on rotors in forward flight. The development of a rational framework is necessary for the accurate predictions of such forces.

Work continued on the calibration of the two-dimensional compressible Navier-Stokes solver. Attention was focused on the evaluation of a two layer eddy viscosity model for steady and unsteady viscous flow calculations. The following cases were considered:

a. Steady viscous flow over a NACA 0012 airfoil at 0.3 Mach number and angles of attack $0^\circ \leq \alpha \leq 10^\circ$ at the Reynolds number 3.6×10^6 .

b. Unsteady viscous flow over a NACA 0012 airfoil at 0.3 Mach number and a Reynolds number of 3.6 x 10 , for the following sinusoidal pitching case:

$$\alpha = 5^\circ + 5^\circ \cos\left(0.4 \frac{tu_\infty}{c}\right)$$

In the above cases the C , C and C predictions were compared with the experimental data of McAlister et al, taken at the US Army Aeromechanics Laboratory, Moffett Field, CA. It was observed that the present solver accurately predicts the aerodynamic loads and surface pressures for the above cases.

Work continued on the development of a three-dimensional unsteady Euler solver for rotor wing flow analysis. Calculations were performed for a rectangular fixed wing undergoing periodic oscillations in the first bending mode. The numerical results agree favorably with subsonic doublet lattice techniques. Currently the above solver has the capability to handle a variety of rotor blade motions such as combined pitching and flapping motions.

The development of the zonal procedure for computing unsteady viscous flows was completed. This procedure permits the confinement of the computation field to the viscous part of the overall flowfield. For flows containing massive separated regions, the zonal procedure permits the several viscous components of the flow, i.e.,the boundary layers, the recirculating region, and the wake, to be computed separately. The procedure requires no iterative matching of the various flow components that co-exist in the flow and is ideally suited for high Reynolds number flow. With this procedure, the computer time requirements is insensitive to the Reynolds number of the problem. A user oriented computer pprogram has been prepared for computing external flows past airfoils.

Concurrent with the development of the computational procedures, a viscous theory of aerodynamics was used in the study of several problems. It was demonstrated that this theory permits the contributions of various flow elements to be identified individually and their relative performance assessed. Efforts have been initiated to apply this theory in studies of the dynamic stall problem. The aim is to improve the understanding of the physical process involved in the complex unsteady rotor aerodynamic problem through a coordinated theoretical and computational effort.

Task 5. Studies of Airframe Flow Field in Forward Flight
J.E. Hubbartt, H.M. McMahon, K.D. Engelhardt,
E.V. Horowitz, & D.R. O'Neil

The overall objective for this task is the validation of a practical theory for predicting the interactions between the rotor and airframe flow fields. Existing analyses is tested against experimental data and modifications made to validate a practical theory.

The following major goals were achieved during this reporting period:

1. Fabrication of a fixed pitch, untwisted rotor blade was completed.

2. Fabrication of the cylindrical fuselage model was completed and equipped with pressure measuring instrumentation.

3. Two supports for the fuselage model were fabricated. One of these is a sting support which provides access to the instrumentation in the model.

4. The rotor blade and drive shaft assembly were balanced and it has been established that the system functions very satisfactorily up to the design speed of 2400 RPM. Small amplitude, resonant vibration occurs at two critical speeds which are near 1400 and 1800 RPM, but these can easily be excluded from steady state operations.

5. Major components of the computer software used for instrument control, data retrieval, and data analysis were developed and checked.

6. Initial validation tests were completed. In these tests, mean pressures and traces of instantaneous pressures were measured for a number of different geometric positions of the model, advance ratios, and rotor speeds. The test results show that the

performance of the overall facility is excellent, that the effect of the rotor flow on the flow over the model is very significant and qualitatively as expected, and that the data which can be generated from this facility will provide an excellent challenge for and test of analysis.

7. The panel method contained in the Freeman code for predicting the superimposed rotor wake and freestream flows has been adapted to the Georgia Tech computer and checked. Also, progress has been made in making the vortex tube model of this code operational.

8. A hydraulic lifter for the LDV was selected and purchased and it has been demonstrated that the LDV can be satifactorily transported from the Nine Foot Static Thrust facility and mounted on the elevated platform of the Nine Foot Wind Tunnel Facility.

As a result of the progress made during this period, the forward flight facility is now operational and of proven capability. Based on wind tunnel calibration tests it has been decided that honeycomb will be installed in the wind tunnel ducting upstream of the test section before proceeding with a detailed test program.

Additional efforts are focused on considering various methods of seeding the wind tunnel flow for LDV measurements, gaining experience with LDV measurements, designing and fabricating a rotor force balance, modifying an existing wind tunnel probe actuator, preparing for flow visualization tests, and making existing computer codes operational.

At this time, acquisition of the Clark and Maskew Code for fully coupled rotor and airframe flows is still pending. NASA Ames has not released the code because the documentation report is yet incomplete.

II. Structures

Task 1. Structural Dynamic System Identification
S.V. Hanagud, J.I. Craig, M. Meyyappa,
Y. Cheng, C. Grimmell, M. Obal, & D. Stuber

The purpose of this task is to develop an approach to advance the state of the art in airframe structural dynamic modelling. Development of applicable system identification techniques - the mathemetical model of the system of interest - and improved physical models are the basis for this research.

During the last reporting period a technique was developed for identifying structural dynamic systems with generalized or non-proportional damping. This technique has now been improved by minimizing the constraints imposed on the objective function of the identifying procedure. The orthogonality conditions are implicitly satisfied.

In this procedure, it is not necessary to explicitly impose the orthonogality conditions. The developed technique has been validated by 1) experimental results, and 2) analytically derived psuedo-results . The experimental results on a cantilever beam were generated at Georgia Tech. This improvement and validation were included in a paper presented to the 25th AIAA/ASCE/ASME/AHS Structures, Structural Dynamics and Materials Conference in Palm Springs, CA.

A second generation structural dynamic physical model was fabricated during the past project period. Modal testing of the models is now in progress. Results from the analysis will be used to identify the mass, damping, and stiffness matrices by using both the published and the developed identification techniques.

The role of identification techniques in optimum design of structures is being explored. This is important because the finite element models that are used in optimizing structural dynamics designs are changed by identification procedures and, to some extent, by the inclusion of damping. Preliminary work is also in progress in the field of structural dynamic design modifications by the use of identification techniques.

A review paper on structural dynamic identification techniques was presented at the Southeastern Conference on Theoretical and Applied Mechanics.

Task 2. Crashworthy Characteristics of Composite Rotorcraft Structures
S.V. Hanagud, S. Chandrashekara, & P. Sriram

The objective of this task is to do basic research work to develop improved techniques and procedure for designing crashworthy composite structures for rotorcraft. This objective includes the development of testing techniques and optimization of the crashworthy designs under the constraints of weight restrictions, cost and performance requirements.

The first phase of static post-buckling tests of composite sandwich specimens has been completed. These sandwich structures have composite faceplates made of either graphite-epoxy or kevlar-epoxy. This phase has considered the effect of two extreme boundary conditions on the postbuckling behaviors and eventual energy absorbing capabilities. The examination of the boundary conditions was initiated to understand the mechanisms of buckling at the intersection of cross beams that are likely to be concentrated in a subfloor structure. This phase of the study also included a study of hybrid core materials.

Preliminary work has been initiated in the field of post buckling studies. This study has used kevlar-epoxy sandwich plates. Some work has also been done in the study of "g" forces experienced by an occupant of a seat when the seat is dropped from selected heights. The investigation has included the reduction of the "g" loads by use of energy absorbing materials.

A model of a composite external fuel tank has been designed and fabricated and drop tests are being planned at present. Work is now in progress in manufacturing non-sandwich energy absorbing structural elements.

Another research program within this task is to develop analysis techniques to understand both the (a) static and dynamic postbuckling behavior of the composite sandwich structures ond non-sandwich structural elements, and (b) the transient dynamic response of the structure during impact. A finite deformation finite element computer code has been developed. At present, the static postbuckling behavior is being simulated and the analysis technique based on the principal of incremental virtual work, Kirchoff-Treftz stress description, three dimensional compatible isoparametric elements, inclusion of both geometric nonlinerarity and material nonlinearity, a penalty function approach, and optimized equilibrium iteration technique.

The transient dynamic response program developed during the last project period is being tested on specific structures under transient compressive loading. The testing of the program on specific finite deformation problems has resulted in a paper that will be published in the International Journal of Nonlinear Mechanics. Another paper in the field of experimental study of postbuckling behavior of the composite sandwich panels was presented at the 12th Southeastern Conference on Theoretical and Applied Mechanics.

III. Aeroelasticity

Task 1. Helicopter Vibration Suppression Techniques
G.A. Pierce, V. Anand, J. Jonnalagadda,
A. Sareen, D. Taylor, & R. Tipton

This program is intended to develop and validate a comprehensive vibratory loads analysis for the design evaluation of vibration suppression techniques. The loads analysis will be applicable to nonuniform multi-bladed systems with teetering, articulated, hingeless or bearingless hub constraints. Special emphasis will be placed on blade structural dynamics, hub and mast dynamics, impedance of the rotor/airframe interface, and unsteady blade aerodynamics. The vibration suppression techniques to be considered will include higher harmonic control, blade mounted absorbers, hub mounted absorbers, and aeroelastic tailoring.

The previously reported modification to the blade equations has resulted in the reformulation of the transformation matrix between the deformed and undeformed coordinates. The previous analysis developed under this task utilized the blade equations of Hodges and Dowell which showed the importance of nonlinear structural and inertial terms on the dynamic response of the blade. Their procedure in deriving the blade equations of motion involved the use of a transformation matrix between the deformed and undeformed coordinate systems. The transformation matrix was obtained using a lag-flap-pitch rotational sequence in terms of Euler angles. Using the Euler-Bernoulli hypothesis for long slender beams, they could represent the final position of a material point of the elastic blade in terms of three displacements along the three undeformed axes and a fourth variable which would fix the relative orientation of the blade cross-sectional principal axes in its plane.

Kaza and Kvaternik showed that the form of the final blade equations was dependent on the rotational sequence used in obtaining the transformation matrix. It is felt that the confusion regarding these differences in final equations using different rotational sequences is due to defining the torsional variable more as a mathematical quantity rather than as a physical angle. This prompted us to take another look at the derivaton of the blade dynamic equations by defining the torsional variable as a physical angle. It may be noted that the transformation matrix is obtained without making use of an Euler-angle transformation. Also, the resulting torsional curvature coincides with that obtained by Wauer wherein the same is obtained through use of classical Euler angles.

Kaza and Kvaternik in their derivation of blade equations in forward flight represented the cyclic pitch variations to be occurring about the undeformed system so that the variations can be incorporated through a coordinate transformation. It is proposed to derive the blade dynamic equations using a variational approach. Also, unsteady aerodynamic effects and induced velocity distributions derived from undistorted and distorted (prescribed) wake representations will be included. The resulting equations may be used for either stability or response analysis to be correlated with experimental results.

FACILITIES/EQUIPMENT

I. Laser Doppler Velocimeter Data Acquisition System
N.M. Komerath, R.B. Gray, J.E. Hubbartt, & H.M. McMahon

During this reporting period the following goals were acheived:

1. Installation and testing of the two-component LDV system.

2. The data analysis package was expanded to enable rotor synchronized sorting of data on two simultaneous channels. In addition, the azimuthal resolution of the data can now be varied by the operator.

3. Studies were conducted to develop a suitable seeding procedure. Based on this experience, a spray nozzle with a resonator cavity was developed to enable generation of clouds of water droplets without causing significant interference to the flow field.

4. The ability to make measurements up to 2186 mm away from the focusing lens and through a plexiglas window in the back scatter mode was demonstrated.

5. The flow field downstream of the tip of a rotor blade was surveyed with the blade revolving at 1000 RPM. Axial and radial components of the velocity vector were obtained as functions of the rotor azimuth by ensemble averaging. By moving the focal point to an azimuth location 90 degrees away, the axial and tangential components were also obtained.

6. The entire LDV system was transported from the nine-foot hover facility to the test section of the forward flight facility, thus demonstrating the transportability of the data acquisition system.

7. Efforts are underway to develop specialized data acquisition software to take advantage of high seeding rates by gathering large blocks of data continuously. It is expected to be a valuable tool for studying and reducing possible low-frequency perturbations in the flow-field.

II. Nine-Foot Static Thrust Facility
R.B. Gray

The facility was designed to provide a laboratory-controlled environment for testing model helicopter rotors up to 4.5 feet in diameter in hovering flight. The LDV system described above is being used in this facility for Aerodynamics Task 1. This facility has also been used for Aerodynamics Task 2. The updating of this facility was to include the purchase of a modern data acquisition system and factory reconditioning of the mercury slipring assembly. Neither item has been a pressing matter. The reconditioning of the sliprings has been delayed to permit the testing to continue. The data acquisition system was originally scheduled for the third year.

III. Structural Dynamic System Identification Facility
S.V. Hanagud & J.I. Craig

Further development of the identification test facility included the evaluation of a data acquisition system. The systems evaluated were a B & K two channel system, a four channel Wave Tuck Nicolet system, the Genrad system expandable to 16 channels, and the Zonic system, also expandable to 16 channels. An eight channel Genrad system was acquired. Some of the features of the system include variable bandwidth, 1 MB core memory, 10 MB Winchester hard disk, 0.5 MB floppy and SDRC Modal-plus software. Test equipment now on order are a tri-axial accelerometer, force transducers, miscellaneous accelerometers, power supplies, and pre-amps.

IV. Transient Dynamic Stress Analysis Facility

S.V. Hanagud & J.I. Craig

A dynamic drop test facility has been designed and fabricated. This constitutes the first phase of the development. This phase uses the concept of free fall of a guided mass. The facility can use up to a 50 lb mass and obtain a velocity of 35 feet per second. A 6-inch outer-diameter guide tube for the mass is supported in position within an existing structural test rig and a thick subfloor under the facility provides an excellent base for test fixtures. The fabricated test facility has been used for preliminary tests of composite sandwich structures.

The transient dynamic data capturing system is undergoing design. Some instrumentation has been acquired and the design and installation of the data acquisition system is in progress.

V. Nine-Foot Wind Tunnel Facility

J.J. Harper, J.E. Hubbartt, H.M. McMahon, & S.S. Kleinhaus

All instrumentation necessary for wind tunnel operation as well as for measurement of forces, pressures and velocities has been installed. The necessary software for computerized data acquisition has been written and checked.

Calibration of flow angularity in the test section was performed after installation of the flat floor and ceiling. These measurements disclosed the presence of a streamwise vortex located at approximately the center of the test section. Changes in the orientation of the anti-swirl vanes located downstream of the tunnel fan did not eliminate this vortex. Accordingly, it has been decided to install a honeycomb in the settling chamber just upstream of the test section. The necessary drawings have been prepared and the honeycomb will be installed in July 1984. Following this, the test section flow and the wind tunnel balance will be calibrated.

VI. Aeroelastic Rotor Test Facility

G.A. Pierce, S.S. Kleinhaus, J.A. Humphries, & A. Sareen

The primary purpose of this new facility is to permit large-scale testing of rotor systems. Such tests will be concerned with steady and unsteady aerodynamic phenomena, structural dynamic response behavior, and evaluation of vibration suppression techniques. Model rotor systems of eight foot diameter can be accommodated. The initial test program will include dynamically excited aeroelastic models which have been Froude scaled in support of Aeroelasticity Research Task 1 on helicopter vibration suppression.

Structural and mechanical construction of the facility was completed and first operational tests without rotor were performed on January 31, 1984 throughout the speed range up to 1800 RPM. In April, operational tests with a two-bladed full-scale tail rotor were carried out creating airflow through the test stand for the first time. In an additional test, data from flapwise-bending strain gage bridges on that rotor hub were channelled through the mast and slipring assembly for display in the control room.

A full scale mock-up of a conceptual Froude scaled bearingless rotor was built to explore manufacturing techniques for individual components. To gain the necessary hands-on experience in making composite lay-ups, a special project was initiated with a senior student. This effort included the lay-up of small flat samples for curing tests as well as long spar elements. Curing was performed by the Grumman Aerospace Corporation, Milledgeville, GA. In a simultaneous effort, attention was focused on the design and fabrication of the model rotor blades and hubs.

The initial dynamic excitation system will consist of a set of equally spaced (in azimuth) stationary air jets which are aligned normal to the tip path plane. This steady airflow will be seen by the rotating blades as a periodic gust excitation at integral multiples of the rotational speed. Preliminary design of this system has begun with an analytical estimate of acceptable gust velocities to determine the required mass flow to size the plumbing. The air supply which is currently in place consists of a 1,000 cubic foot tank which is supplied by a 300 SCFM compressor at 125 psi.

In a parallel effort, a one-sixth scale model of the Aeroelastic Rotor Test Facility and containment room is being constructed. The model is intended to simulate the recirculation flow pattern throughout the facility and provide an economical means of evaluating potential modifications for flow improvement. This pilot facility has been completed except for installation of the rotor and drive system. After the facility model is operational, tests will be conducted to measure thrust and visualize the flow.

A proposal was submitted to the Department of Defense "DoD-University Research Instumentation Program" for acquisition of equipment to permit simulation of higher harmonic controllers, expand the data acquisition capability of the facility, and permit on-line frequency analysis of recorded data. The proposal was accepted to be funded for $300,000 in FY 85. Of these monies, $60,000 in matching funds will be provided by Georgia Tech.

UPDATED AND NEW COURSE DEVELOPMENT

The status of the courses to be updated and the new courses to be developed are shown in Table 1. The updating of courses has been completed. Those new courses that were developed during earlier reporting periods or have a comment in the Remarks column that they have already been taught have been reported on in the corresponding progress report for that period. The status of the remaining courses is given below.

Aerodynamics of the Helicopter III
R.B. Gray

This course is to be an introduction to vortex wake analyses of both classical and finite-bladed rotors, for both hovering and forward flight conditions. An outline of the course has been prepared and the course will be further developed and taught during the Summer of 1984.

Rotorcraft Design I
D.P. Schrage

This course consists of V/STOL technology concepts and test experiences with experimental prototypes. Following this review, promising rotorcraft concepts are discussed and students are introduced to closed form and graphical methods for rotorcraft conceptual design. Problems are assigned addressing material covered in class and a final individual design project highlight the course. Fourteen students were enrolled during Spring 1984 with an additional three students auditing the course.

Rotorcraft Design II
D.P. Schrage

The course is based around requirements issued in a Request for Proposal (RFP) for a Public Service Helicopter (PSH). Unlike Rotorcraft Design I, the emphasis in this course is on the utilization of computerized preliminary design methods. Two V/STOL sizing and performance programs, HESCOMP and VASCOMP, are used to size the rotorcraft to meet RFP requirements and calculate the performance. Another code, C81, is utilized to calculate trim and stability derivatives. Students are separated into teams and each team is given different requirements weighting criteria. All students in a team are required to give an oral presentation and submit a final design report. This course will be taught in the Summer of 1984.

VISITS/COMMUNICATIONS

1. R.B.Gray

Bell Helicopter Textron, February 23-26, 1984

The purpose of this visit was to discuss areas of mutual interest and provide an overview of the Center of Excellemce program to Bell personnel.

Washington D.C., March 12, 1984

This trip was to attend a meeting of the Directors of the Centers of Excellence for Rotary Wing Aircraft Technology. Dr. Robert Loewy of RPI and Dr. Albert Gessow of University of Maryland were in attendance.

American Helicopter Society Annual Forum, Crystal City, VA, May 13-20, 1984

The purpose of this trip was to represent Georgia Tech and the Center of Excellence at the 41st Annual Forum of the American Helicopter Society. Professor Howard McMahon and eleven graduate and undergraduate students also attended. Staffers of the GT booth described the curriculums, unique research facilities, and the available research abilities of the Center of Excellence to Forum attendees.

The responsibility to appear on the AHS Education Commitee was also fulfilled.

92nd ASEE Annual Conference, Salt Lake City, UT, June 24-28, 1984

The purpose of this trip was to present a paper on the graduate rotorcraft programs at Georgia Tech.

2. J.I. Craig

Washington, D.C., December 8, 1984

This visit was a demonstration and review of GENRAD structural dynamics analysis equipment for use in CERWAT structures research tasks. Not previously reported.

Bell Helicopter Textron, February 23-25, 1984

This visit was to present a CERWAT program review and discuss research areas of mutual interest.

Sikorsky Aircraft and Kaman Aerospace, February 29-March 1, 1984

This visit was to conduct CERWAT research program discussions with the technical staff of both companies.

3. S.V. Hanagud

Bell Helicopter Textron, February 23-25, 1984

The purpose of this trip was to discuss research areas of mutual interests with Bell engineers. In particular, Mr. Warren Young, Mr. Robert Lynn, and Mr. Larry Jenkins were especially hospitable. Mr. Ron Balke presided as host for discussions of structural dynamics and crashworthiness.

A discussion with Mr. Micheal Smith focused on structural dynamics, nonlinearity, and the design modifications. Mr. Victor Berry followed with discussions involving crashworthy design of composite rotorcraft.

Kaman Aerospace, March 1, 1984

This visit was to present the CERWAT program specific to structural dynamic system identification and to explore areas of mutual interest with Mr. Alex Berman and the Kaman modal testing group led by Mr. Ed Nagy and Mr. Bill Flanly. In particular, the limitations of the "state of the art" of structural dynamic system identification techniques and the need for further research were brought out. In the experimental field the accuracy achievable by the presently available instrumentation were discussed.

Sikorsky Aircraft, Stratford, CT, March 1, 1984

This meeting was to interact with Sikorsky engineers in the discipline of structural dynamics. A rather lengthy discussion ensued on closely spaced modes and the potential that is offered by the structural dynamic system identification techniques. Crashworthy rotorcraft design was another topic of interest.

National Aeronautical Laboratory, Bangalore, India, March 8-26, 1984

Review lectures were presented in the field of structural dynamic system identification and modal identification. The lectures introduced both the basic concepts and current published research.

NASA Langley Research Center, April 24-25, 1984

The purpose of this visit was to attend the symposium on recent experiences in multi-disciplinary analysis and optimization. Of particular interest was the rotorcraft optimization session and lectures giving an overview of current research activities in other fields.

Interaction with government and industry engineers included discussions with Mr. Dick Bennett of Bell Helicopters, Dr. Dave Banerjee of Hughes Helicopters, Dr. Venkayya of WPAFB and Mr. Alex Berman of Kaman Aerospace Corporation. Most interaction centered on the subject of the role of optimization in the study of rotorcraft structures.

An interesting exchange took place with Dr. Rau of the San Diego State University concerning research work in multi-objective functions.

AIAA/AHS Structural Dynamics and Materials Conference and Hughes Helicopters, Inc, Los Angeles, CA., May 16-19, 1984

A paper entitled "Identification of Systems with Non-proportional Damping" was presented. Following the conference, a visit to the Stanford Research Institute, Menlo Park, CA, was arranged by Dr. Lindburgh and Dr. Alex Florence to discuss their work in the field of dynamic buckling studies.

Dr. Robert Wood and Mr. Grant Parker arranged a meeting at Hughes Helicopters, Inc. to discuss their ongoing work in structural dynamics, crashworthiness, and optimization.

Renssalear Polytechnic Institute, May 24-25, 1984

The purpose of this visit was to attend and present a paper to the Army Conference on Numerical Methods. The paper was entitled "A Two-Step Version of the Strong-Gottlieb Techniques for Deformable Lagrangian Meshes". The technique described was developed and tested on crashworthy structures.

4. J.E. Hubbartt

NASA Ames Research Center

Letter (January 11, 1984) and telephone call (March 26, 1984) to Mr. Charles Smith requesting a copy of the AMI computer code for interacting rotor/airframe aerodynamics. A copy of the code will be sent from NASA on magnetic tape upon release of the documentation report.

Bell Helicopter Textron, February 23-25, 1984

This visit was to identify research efforts of mutual interest and to present the CERWAT program to Bell engineers.

Bell Helicopter Textron, April 21, 1984

Telephone call to Mr. Tom Wood to clarify the problem associated with the interaction between the jet exhaust flow with IR suppression and the rotor. The importance of this interaction was emphasized by Mr. Wood and others during the plant visit in February.

USA AVSCOM RTL, NASA Langley Research Center, May 7, 1984

Telephone call to Mr. John Berry requesting a printout of the RWAKE subroutine contained in the Freeman computer code for interactive rotor/airframe aerodynamics. This printout has been received.

5. H.M. McMahon

American Helicopter Society 1984 Forum, Crystal City, VA
May 15-19, 1984

This purpose of this trip was to represent the Georgia Tech CERWAT program at the AHS Forum and to attend technical presentations aligned with CERWAT research efforts.

6. G.A. Pierce

Bell Helicopter Textron, February 23-25, 1984

The Bell engineering facility was visited to discuss mutual research interests and obtain information on detailed design and manufacturing techniques and concerns associated with dynamically scaled rotor systems.

Hughes Helicopters, Inc., Mesa, AZ, May 9-10, 1984

A review and demonstration of the Higher Harmonic Control Program was attended at the HHI facility. Technical discussions were held with Dr. Bharat Gupta, Chief of Dynamic Test and Evaluation, on areas of mutual interest wherein research at Georgia Tech could be supported by Hughes IR&D funds.

Univ. of Federal Armed Forces, Munich, W. Germany, May 21, 1984

Mr. Ulrich Leiss of the Institut fuer Luftfahrtechnik, Hochschule der Bundeswehr, visited Georgia Tech to discuss our work on the unsteady aerodynamics of rotor blades.

7. D.P. Schrage

Bell Helicopter Textron, Ft. Worth, TX, February 23-25, 1984

After an overview given by Dr. R.B. Gray, specific discussions took place with Mr. Troy Gaffey, JVX Project Engineer, Mr. Dick Spivey, JVX Marketing Manager, and Dr. Richard Bennett, Research Engineer. These discussions involved tilt-rotor technology and the ability to obtain material that could be used to incorporate tilt-rotor design into the rotorcraft design course. Mr. Gaffey provided a list of tilt rotor research in all disciplines and they in turn were provided to the appropriate CERWAT faculty members. Bell Helicopter Textron will make available the Generalized Tilt Rotor (GTR) Computer program which provides a digital simulation of the tilt-rotor in flight.

USA AVSCOM Applied Technology Laboratory, Ft. Eustis, VA;
Structures Laboratory, NASA Langley, February 27, 1984

Following the CERWAT overview, discussions took place with Dr. Gene Hammond, Aeromechanics Branch Chief, Mr. Ed Austin, and Mr. Bud Carper, who heads up the survivability area. Specifically, different analysis tools that might be available to CERWAT were dicussed. These include C-81, DYSCO, and DNAM. Mr. Carper was contacted concerning ongoing work at the Engineering Experiment Station.

At NASA Langley, discussions with Mr. Dick Long, Director of the Structures Laboratory, took place. These centered on possible CERWAT Fellows from the Structures Lab. Following this meeting, a tour of the V/STOL tunnel was presented and discussions with Dr. Gene Bingham on rotor blade design optimization were accomplished. Potential areas of interface between CERWAT and the laboratories were discussed throughout the day.

Boeing Vertol Co., Essington, PA, February, 28, 1984

Following a CERWAT overview, Mr. Euan Hooper, Chief of Technology, arranged meetings with Mr. Nick Albion on flight controls, Mr. Kaydon Stanzione on rotorcraft design and HESCOMP, and a tour of the BV wind tunnel and model shop. Discussions of possible CERWAT-BV interaction on a research program to investigate higher harmonic pressure distributions and their influence on rotor blade dynamic response took place. Boeing Vertol has participated in the Georgia Tech Undergraduate Co-op Program and seemed interested in the Graduate Co-op program.

USMA, West Point, NY, February 29, 1984

The purpose of this visit was to present a CERWAT program overview and to evaluate the USMA Rotorcraft Design course that was formulated by Dr. Schrage two years ago.

Sikorsky Aircraft, Stratford, CT, March 1, 1984

Following a CERWAT overview, Drs. Craig and Hanagud met with engineers working in the disciplines of structural test, crashworthiness, and dynamics. Dr. Dave Jenney, Chief of Technical Engineering, and Mr. Pete Arcidiacono, Aeromechanics Branch Manager, discussed the graduate co-op program with Dr. Schrage. They were strongly in favor of the program.

A meeting was then held with Mr. Ted Carter, Director of Technology, to discuss the Georgia Tech Rotorcraft Design course. Mr. Carter mentioned that he was putting together a course for a local university and that the material would be sent as soon as completed.

Kaman Aerospace, Bloomfield, CT, March 1, 1984

The purpose of this visit was to present the CERWAT program to Kaman engineers and to discuss possible areas of interaction, most notably in the discipline of structural dynamics analysis and testing. A meeting with Mr. Alex Berman and Dr. S.Y. Chen followed which focused on the Dynamic Coupling Program (DYSCO) developed at Kaman. This fully interactive executive control system for modeling dynamic and aerodynamic phenomena is an excellent tool for all the CERWAT disciplines and for coursework. Mr. Berman provided much material on the program, including a user's manual, and stated that Kaman would make it available to Georgia Tech.

US Army Aviation Systems Command, St. Louis, MO, March 2, 1984

After making a courtesy visit with Mr. Charles Crawford, Technical Director and BG Ronald Andreson, Deputy Commander for Research and Development, a CERWAT overview was presented to approximately 30 AVSCOM engineers. Information on both undergraduate and graduate co-op programs were provided to the AVSCOM Co-op Coordinator, Ms. Jerry Franzoi, and Georgia Tech is now officially on the roles as a AVSCOM Co-op organization.

Hughes Helicopters, Mesa, AZ and Culver City, CA, March 13-23, 1984

This visit was to represent the CERWAT at the on-site IR&D review in Mesa, AZ, and to present a CERWAT overview to the engineers at the Culver City facility. Increased interaction was discussed concerning areas of mutual interest and the initiation of a Graduate Co-op program.

American Helicopter Society 1984 Forum, Crystal City, VA May 11-21,1984

This visit was to represent Georgia Tech and CERWAT at the annual American Helicopter Society Forum and to attend technical presentations on evolving rotorcraft research applicable to efforts under way at Georgia Tech.

8. J.C. Wu

USA AVSCOM RTL, Aeromechanics Lab, Moffett Field,CA, June 23, 1984

The purpose of this visit was to present a lecture at the US Army Aeromechanics Laboratory and to exchange research information.

9. S.S. Kleinhaus

Weyerhause, Columbus, MS, Jan 11-13, 1984

This visit was made to balance the main shaft for the Aeroelastic Rotor Test Facility.

Bell Helicopter Textron, Ft. Worth, TX, February 13-14,1984

This meeting was to discuss rotor and model design in support of the fabrication of the bearingless main rotor system ongoing at Georgia Tech.

Boeing Vertol, Philadelphia, PA, February 28, 1984

The purpose of this visit was to discuss bearingless rotor design with the Boeing Vertol engineers. This aided in the design and fabrication of the model bearingless rotor system now being constructed at Georgia Tech.

Grumman Aerospace Corporation, Milledgville, GA, April 18, May 31, & June 14, 1984

These visits were to deliver and pickup composite lay-ups for the bearingless main rotor system cured at the Grumman facility.

Sikorsky Aircraft, Stratford, CT, May 2, 1984

This visit was to discuss model blade design and instrumentation procedures with Sikorsky engineers in support of the bearingless main rotor manufacturing effort.

US Army Aviation Center, Ft. Rucker, AL, June 26, 1984

The purpose of this visit was to screen the property disposal yard for helicopter parts the Center could use in research or coursework.

SIGNIFICANT EVENTS

Rotorcraft Design Program, January 4, 1984

Dr. Daniel P. Schrage, formerly Director of Advanced Systems, USA AVSCOM, arrived on campus on January 4, 1984. He is the Center's Rotorcraft Design Professor and is responsible for developing and teaching design courses in this area. The courses will be taught for the first time in the Spring and Summer of 1984. Dr. Schrage is also the faculty advisor for two teams of undergraduate and graduate students who prepared entries for the American Helicopter Society and the Boeing Vertol Company Rotary Wing Design Competition. In addition, he will be involved in the educational and research programs in aeroelasticity and will bring the Center a capability in flight mechanics.

Visit to Bell Helicopter Textron, February 23-25, 1984

Mr. Robert Lynn, Senior Vice President for Research and Engineering arranged a comprehensive visit for J.I. Craig, R.R. Gray, S.V. Hanagud, J.E. Hubbartt, G.A. Pierce, D.P. Schrage and J.C. Wu. The program included briefings of the activities at Bell and the programs of the Center; a tour of the production line, the composite manufacturing facilities, and the test facilities; individual conferences; and a final wrap-up session. Areas having excellent potential for future interactions were determined.

Organizational Meeting of the AHS Chapter, March 8, 1984

The Atlanta Chapter of the American Helicopter Society was organized on March 8, 1984. The first dinner meeting was held on April 26, 1984, with 29 members and guests in attendance. The speaker was Richard F. Spivey, Manager of Tilt Rotor Business Development, Bell Helicopter Textron.

Composite Construction of Model Rotors

A significant effort is underway to develop a capability within the Center for manufacturing model rotor systems from composite materials. The following companies have been very helpful in providing advice and assistance in this area:

Bell Helicopter Textron, Ft. Worth, TX
Boeing Vertol Company, Philadelphia, PA
Grumman Aerospace Corporation, Milledgeville, GA
Sikorsky Aircraft Division, UTC, Stratford, CT

Donation of Equipment

Bell Helicopter Textron donated a Model 212 tail rotor system to be used for initial testing and check-out of the Aeroelastic Rotor Test Facility.

Computer Programs

The following computer codes have been received and are being used in various aspects of the Center's activities.

HESCOMP/VASCOMP	NASA/Boeing Vertol	Rotorcraft Sizing and Performance
C81	ARMY/Bell Helicopter	Comprehensive Helicopter Analysis
FLYRT	Hughes Helicopters	Flight Mechanics

DNAMO5	ARMY/Bell Helicopter	Vibration Analysis
SSP1/SSP2	ARMY	Single Rotor Helo Sizing and Performance
GTR	Bell Helicopter	Tilt Rotor Flight Mechanics Program

Presentations

The following seminars were presented and well received at the Georgia Tech Center of Excellence:

"Crash Survivability in Helicopters and General Aviation Accidents", Dr. R.G. Snyder, University of Michigan, February 14, 1984

"Tilt Rotor Technology and the JVX Program", Mr. Richard F. Spivey, Bell Helicopter Textron, April 26, 1984

"The Dynamic Stall of Airfoils", Dr. N.L. Sankar, Georgia Institute of Technology, April 27, 1984

"Laser Velocimetry in the Wake of a Rotor in Hover", Dr. Narayanan Komerath, Georgia Institute of Technology, May 11, 1984

"A Generalize Coupling Technique for the Dynamic Analysis of Structural Systems", Mr. Alex Berman, Kaman Aerospace, May 30, 1984

CERWAT RESEARCH COORDINATOR

Mr. Stephen A. Meyer has accepted our offer to be the Center's Research Coordinator. His primary responsibility is to provide assistance to the Technical Director and Administration/Finance Director in coordinating rotorcraft research efforts and in providing liaison with the government, industry and professional societies.

CENTER OF EXCELLENCE FOR ROTARY WING AIRCRAFT TECHNOLOGY

ACADEMIC PROGRAM DEVELOPMENT

Discipline	Course	Title	Status: Updated	Status: New, 1st Year	Status: New, 2nd Year	Status: New, 3rd Year	Remarks	Instructor
Aerodynamics	4600	Computational Aerodynamics		X			Scheduled for Summer of 1984	Sankar
	6012	Viscous Flow III		X	X		Summer of 1983 - 7 students	Lekoudis
	6022	Adv. Comp. Flow Theory II	X				Spring of 1983 - 9 students Spring of 1984 - 13 students	Lekoudis Sankar
	6402	Aerodynamics of the Helicopter III			X	X	Scheduled for Summer of 1984	Gray
	6802	Numerical Fluid Dynamics III			X		Fall of 1983 - 11 students	Wu
	6810	Unsteady Aerodynamics				X	To be developed	Wu
Aeroelasticity	6030	Adv. Potential Flow I	X				Fall of 1982 - 20 students Fall of 1983 - 17 students	Pierce Pierce
	6031	Adv. Potential Flow II	X				Winter of 1983 - 17 students Winter of 1984 - 19 students	Pierce Pierce
	6200	Adv. Aeroelasticity I	X				Spr. 1983 - 8; Spr. 1984 - 11	Pierce
	6201	Adv. Aeroelasticity II	X				Offered on demand	Pierce
	6202	Exp. Aeroelasticity	X				Summer of 1983 - 7 students	Pierce
Design	6350	Helicopter Design I			X		Spring of 1984 - 13 students	Schrage
	6351	Helicopter Design II				X	Scheduled for Summer of 1984	Schrage
Structures	4115	Intro. to Fiber Reinforced Composites				X	To be developed	Rehfield
	4116	Manuf. Composite Structures				X	To be developed	Rehfield
	6106	Finite Deformations of Aircraft Structures			X	X	Under development	Hanagud
	6132	Vib. Measurement and Analysis		X	X		Spring of 1984 - 15 students	Craig Hanagud
	6133	System Identification		X	X		Scheduled for Summer of 1984	Craig

TABLE I

GRADUATE ROTORCRAFT PROGRAMS AT GEORGIA TECH

Robin B. Gray

School of Aerospace Engineering
Georgia Institute of Technology
Atlanta, GA

Abstract

Master of Science and Doctor of Philosophy degree programs in rotorcraft technology are being offered at Georgia Tech in the disciplines of aerodynamics, aeroelasticity, and structures. The programs reflect the development of new courses, experimental facilities, and research projects. The unifying and common activity in all three educational programs is a course sequence consisting of three credit hours in helicopter performance and eight credit hours in rotorcraft design. Experience in the use of computer-aided design tools and graphic work stations is an important part of the design courses. Student financial aid is provided by cooperative programs, research assistantships, and prestigious fellowships. An additional program in flight mechanics is planned. The program is supported by the US Army and is monitored by the US Army Research Office.

Presented at the 1984 ASEE Annual Conference and published in the proceedings, Salt Lake City, UT June 24-26, 1984.

METHOD OF MULTIPLE SCALES AND IDENTIFICATION OF NONLINEAR STRUCTURAL DYNAMIC SYSTEMS

S.V. Hanagud, M. Meyyappa, & J.I. Craig

School of Aerospace Engineering
Georgia Institute of Technology
Atlanta, GA

Abstract

A procedure has been developed to identify the parameters of a nonlinear structural dynamic system with a single degree of freedom. A cubic nonlinearity has been assumed for purposes of illustration. In comparison to the direct identification procedures that depend on (a) the availability of data on all four variables (velocity, acceleration, displacement, and input to the system), and of (b) the formulation of an algorithm that is used to numerically integrate differential equations at each iterative step, the developed procedure requires the data on only one of the field variables and no numerical integration at each step. The input to the system is also treated as an unknown. The results from the perturbation identification procedure have been compared with the results from two direct identification procedures.

Revised for publication in the AIAA Journal.

IDENTIFICATION OF STRUCTURAL DYNAMIC SYSTEMS WITH NONPROPORTIONAL DAMPING

S.V. Hanagud, M. Meyyappa, Y.P. Cheng, & J.I. Craig

Georgia Institute of Technology
School of Aerospace Engineering
Atlanta, GA

Abstract

A method to identify the mass, damping and stiffness matrices from measured modal parameters is discussed. The procedure consists of minimizing a matrix norm of the error in the eigenvalue equation. It is assumed that some of the coefficients of the mass matrix are known a priori. The unknown coefficients of the mass matrix and the coefficients of stiffness and damping matrices are then obtained. Both numerical examples and examples using real experimental data are considered. Cases of proportional and nonproportional damping are discussed.

Presented at AIAA/ASME/ASCE/AHS 25th Structures, Structural Dynamics and Materials Conference, Palm Springs, CA, May 14-16, 1984

A NUMERICAL ANALYSIS FOR BLADE TIP LOADINGS ON A THICK BLADED HOVERING HELICOPTER ROTOR

Thomas Changju Wey

School of Aerospace Engineering
Georgia Institute of Technology
Atlanta, GA

Abstract

An iterative vortex panel method and a simple model for vortex/surface interaction have been developed here to predict the pressure and the velocity distributions over a thick blade rotor.

The whole rotor system is represented by a system of vortices. It includes a bound vortex, a wake vortex system and a freestream vortex. The bound vortex consists of spanwise and chordwise vortex sheets on the blade surface. The wake vortex system is composed of an inner wake vortex sheet, a far-field tip vortex and a near-field tip vortex. The far-field vortex geometry is prescribed from experiments. The inner wake vortex sheet and a first approximation to the blade bound vorticity distribution are computed using a lifting line theory. The near-field tip vortex is computed by imposing the force free conditon. A new set of vorticity values on the blade surface are obtained by computing the tangential velocity induced at the mid-points of each panel on the surface.

The pressure distributions computed by using the present method are in good agreement with the experimental data at the blade pitch angles of 6.18 degrees and 11.4 degrees.

Dr. Wey's PhD dissertation.

A TWO-STEP VERSION OF STRANG-GOTTLEIB TECHNIQUES FOR DEFORMABLE LAGRANGIAN MESHES

Sathya V. Hanagud and H.P. Chen
School of Aerospace Engineering
Georgia Institute of Technology
Atlanta, GA

Abstract

In order to analyze the dynamic responses of elastic-plastic solids with finite deformations, a new numerical technique has been developed. The developed numerical scheme is an explicit finite difference scheme with second order accuracy.

Since the elastic-plastic finite deformation problem is always path-dependent or time-dependent, the response of this problem is most accurately calculated numerically by a step-by-step incremental analysis. A Cauchy stress and an updated Lagrangian approach are chosen to formulate such a problem. In such a formulation, the initially well-arranged meshes distort with increasing time as the body is subjected to finite deformations. Thus, the conventional finite difference schemes for spatial derivatives are no longer suitable. By defining some new contour difference operators, an optimally stable and second order accurate numerical technique has been developed. The scheme is based on the Lax-Wendroff scheme, the modified version of Strang's method due to Morris and Gottlieb, and the MacCormack two-step schemes. This finite difference method is suitable for solving problems where the grid system is not fixed but distorts with time.

Presented at the US Army Conference on Numerical Methods, Renssalear Polytechnic Institute, Troy, NY.

PROGRESS REPORT

1. ARO PROPOSAL NUMBER: 19364-E

2. PERIOD COVERED BY REPORT: 1 JULY - 31 DECEMBER 1984

3. TITLE OF PROPOSAL: A CENTER OF EXCELLENCE FOR ROTARY WING AIRCRAFT TECHNOLOGY

4. CONTRACT OR GRANT NUMBER: DAAG29-82-K-0094

5. NAME OF INSTITUTION: GEORGIA INSTITUTE OF TECHNOLOGY SCHOOL OF AEROSPACE ENGINEERING

6. AUTHOR(S) OF REPORT: R.B. Gray, J.I. Craig, S.V. Hanagud, J.J. Harper, J.E. Hubbartt, S.S. Kleinhaus, N.M. Komerath, S.G. Lekoudis, H.M. McMahon, S.A. Meyer, G.A. Pierce, N.L. Sankar, D.P. Schrage, L.W. Rehfield & J.C. Wu

7. LIST OF MANUSCRIPTS SUBMITTED OR PUBLISHED UNDER ARO SPONSORSHIP DURING THIS PERIOD, INCLUDING JOURNAL REFERENCES:

PAPERS:

"Local Crippling of Thin Walled Composite Structures under Axial Compression", A.D. Reddy, L.W. Rehfield, and R.I. Bruttomesso Presented at the 26th AIAA/ASME/ASCE/AHS Structures, Structural Mechanics and Dynamics Conference, Orlando, FL, April 15-17, 1985

"A Study of the Static Post Buckling Behavior of Composite Sandwich Plates", S.V. Hanagud, H.P. Chen and P. Sriram, Submitted to the International Conference on Rotorcraft Basic Research, Research Triangle Park, NC, February 19-21, 1985

"Identification of Systems with General Damping Matrices", S.V. Hanagud, Y.P. Cheng, M. Meyyappa, J.I. Craig, Submitted to the International Conference on Rotorcraft Basic Research, Research Triangle Park, February 19-21, 1985

"The Prediction of the Flow Around Blade Tips", B. Wake, N. Sankar, S. Lekoudis and R.B. Gray, Submitted to the International Conference on Rotorcraft Basic Research, Research Triangle Park, NC, February 19-21, 1985

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Dr. A.L. Ducoffe, Director
Dr. R.B. Gray, CERWAT Principal Investigator
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"Local Crippling and Postcrippling Behavior of Graphite/Epoxy Thin Walled Airframe Members", A.D. Reddy, L.W. Rehfield and R.I. Bruttomesso, Accepted for proceedings publication of the 1985 American Helicopter Society Forum, Ft. Worth, TX, May 15-17, 1984

"Numerical Solution of Unsteady Viscous Flow past Rotor Sections" by N.L. Sankar and W. Tang, AIAA Paper 85-0129, Presented at the 23rd Aerospace Sciences Meeting, Reno, NV, January 1985

"Solution if the Unsteady Euler Equations for Fixed and Rotor Wing Configurations", N.L. Sankar, B. Wake, and S.G. Lekoudis, AIAA Paper 85-0120. Presented at the 23rd Aerospace Sciences Meeting, Reno, NV, January, 1985.

"Unsteady Aerodynamics of an Airfoil Encountering a Passing Vortex", J.C. Wu, N.L. Sankar, and T.M. Hsu, AIAA Paper 85-0203, Presented at the 23rd Aerospace Science Meeting, Reno, NV, January 1985

"Numerical Solution of Navier-Stokes Problems using Integral Representation with Series Expansions", C.M. Wang and J.C. Wu, AIAA Paper 85-0034, Presented at the 23rd Aerospace Sciences Meeting, Reno, NV, January 1985

"Computational and Theoretical Studies of Blade-Vortex Interaction Aerodynamics using Zonal Procedures", J.C. Wu and N.L. Sankar, ARO Workshop on Blade-Vortex Interactions, NASA Ames Research Center, Moffett Field, CA, Oct. 1984

"Velocity Measurements in the Near Wake of a Hovering Rotor", T.L. Thompson, N.M. Komerath, and R.B. Gray. Abstract submitted to the AIAA 18th Fluid Dynamics, Plasma Dynamics and Lasers Conference, Cincinnati, OH, July 16-18, 1985

"Aerodynamic Interactions between a Rotor and Airframe in Forward Flight", N.M. Komerath, H.M. McMahon, and J.E. Hubbartt. Abstract submitted to the AIAA 18th Fluid Dynamics, Plasma Dynamics and Lasers Conference, Cincinnati, OH, July 16-18, 1985

8. SCIENTIFIC PERSONNEL SUPPORTED BY THIS PROJECT AND DEGREES AWARDED DURING THIS REPORTING PERIOD:

Faculty: J.I. Craig, A.L. Ducoffe, R.B. Gray, S.V. Hanagud, J.E. Hubbartt, S.G. Lekoudis, H.M. McMahon, G.A. Pierce, L.W. Rehfield, D.P. Schrage, & J.C. Wu

Research Engineers: S.S. Kleinhaus, N. Komerath, R. Latham, S.A. Meyer, A. Reddy & N.L. Sankar

Research Associates: J. Caudell & H. Meyer

Post Doctors: V. R. Anand, A. Valisetty, H.P. Chen, M. Meyyappa, & C. Wang

Fellows: Ph.D.: Ronald D. Lowe, Thomas L. Thompson, Dana J. Taylor, Brian Wake.

M.S.: Albert G. Brand, Dimitris N. Mavris

Graduate Research Assistants: Ph.D.: P. Cheng, M. Hashemi-Kia, V.R.P. Jonnalagadda, V.M. Kaladi,O.J. Kwon, C. Raghaven, S. Sarkar, M. Sohn, P. Sriram, N. Weston

M.S.: S.G. Liou

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Faculty: J.J. Harper

Ph.D. Students: E. Horowitz

M.S. Students: P. Georges, M. Obal, D. Pritchard, P. Oliver, D. Stuber

B.S. Students: T. Moore & D. Ngo

DEGREES AWARDED (This reporting period)

NAME	DEGREE-DATE	PRESENT AFFILIATION
D. O'Niel	MS - Sept 1984	Hughes Helicopters, Inc.
D. Pritchard	MS - Sept 1984	PhD Program Georgia Tech Graduate Co-op Hughes Helicopters, Inc.
B. Wake	MS - Sept 1984	PhD Program Georgia Tech

DEGREES AWARDED (Cumulative)

NAME	DEGREE-DATE	PRESENT AFFILIATION
T. Boyd	MS - Sept 1983	US Air Force
C. Boyette	MS - Dec 1983	Hughes Helicopters
C. Brevoort	MS - Sept 1983	Lockheed Georgia
CPT C.N. Cardinal	MS - June 1984	US Army
H.P. Chen	PhD- Dec 1983	Georgia Tech
MAJ M. Clifford	MS - Dec 1982	US Army
J.E. Corban	*BAE- June 1983	Hughes Helicopters, Inc
P.L. Elliot, III	*BAE- June 1983	Boeing Vertol Co.
K. Engelhardt	MS - Sept 1983	Hughes Helicopters, Inc
C. Grimmell	MS - June 1984	General Dynamics
MAJ W.J. Hatch	MS - June 1984	US Army
J.A. Humphries	MS - June 1984	US Air Force
V. Jonnalagada	MS - Sept 1983	PhD Program Georgia Tech
CPT W. McArthur	MS - March 1983	US Army
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T. Parham	MS - Sept 1983	Bell Helicopter Textron
G. Power	MS - Sept 1983	United Technologies Research Center
D. Pritchard	MS - Sept 1984	PhD Program Georgia Tech Graduate Co-op Hughes Helicopters, Inc
J. Rogers	MS - Sept 1983	General Dynamics
S. Sparks	MS - Sept 1983	United Technologies Research Center
T. Thompson	MS - Sept 1983	PhD Program Georgia Tech
R. Tipton	MS - Aug 1983	Sikorsky Aircraft
B. Wake	MS - Sept 1984	PhD Program Georgia Tech
T. Wey	PhD- Dec 1983	------

RESEARCH TASKS

I. Aerodynamics

Task 1. Experimental Studies for Tip Vortex Core Modeling
R.B. Gray, N. Komerath, & T. Thompson

The objectives of this task are to 1) develop a capability for using a two-component laser doppler velocimeter facility and data acquisition system, 2) to measure the flow field near the tip and in the wake of a hovering model helicopter rotor, 3) and to use the resulting data to guide the development of a tip vortex core model for use in free wake analyses for blade loadings predictions. The longer term objectives are to develop a hovering vortex wake analysis which is not as dependent on empirical parameters for describing the tip vortex geometry and to investigate the extension of the vortex wake analysis to low-speed forward flight.

Analysis of the data acquired during this reporting period show a greater repeatability of measurements than the previous reporting period. For a given downstream location in the wake, the radial location and azimuthal occurance can now be specified. A study of the velocity profiles within the core suggests the possibility of counterrotating vortices. This has shown good repeatability and may be due to the tip vortex inducing a vortex sheet (of opposite rotation) on the blade which eventually rolls up and merges with the tip vortex.

Data is currently being plotted at both two and six degrees of resolution. The degree of resolution specifies the width of the azimuthal slots to which particles arriving at the measuring volume are assigned. The velocity of the particles within each slot are then averaged and this averaged value is assigned to the midpoint of the particular slot. It is essential that the slot size be as small as possible in order to accurately model sharp velocity gradients within the core. Due to seeding particle inertia, however, few points are falling in slots near the core. This condition has shown to become especially critical at two degrees resolution with some slots having no measurable particles. Seeding techniques are being studied to solve the problem as it is obviously critical to the completion of the research.

Task 2. Modification of Blade Tip Loading to Improve Hovering Figure of Merit
R.B. Gray & T. Thompson

Measured pressure distributions on the tip of a hovering model rotor blade show a low pressure region which is associated with the roll-up and rearward sweep of the tip vortex over the trailing 50% for the blade upper surface. This low pressure region near the trailing edge contributes significantly to the section pressure drag and hence to the rotor power required. The objective of this task is to explore the possibilities of improving performance by modifying the tip pressure distribution.

This research task has been completed and a final report will be prepared.

Task 3. A Procedure for Computing Rotor Blade/Tip Vortex Interactions
R.B. Gray, S.G. Lekoudis, B.E. Wake

An iterative, lifting surface, vortex panel method has been developed for computing the surface pressure distribution in hover on a thick rotor blade with a half body of revolution tip. The basic viewpoint underlying the development of this method was to assess the viability of an inviscid, incompressible flow model with the implied classical theorems while employing empiricisms which appear to be reasonably well accepted. The investigation was one of numerical experimentation and has been completed and a paper is in preparation.

The long term objective of this task is the development of a capability of obtaining solutions for the blade pressure distribution without as much empirical input and with the inclusion of viscous and compressibility effects. An Euler code has been converted from a wing code to a rotor code. The three dimensional Euler equations are solved in conservation form for the flow around arbitrarily shaped rotors. The equations are solved using a hybrid implicit-explicit finite-difference scheme. An alternating direction implicit algorithm is used in the airfoil planes and the spanwise derivatives are explicitly evaluated. The solution is based on a time marching procedure. With the hybrid scheme both the speed of explicit schemes and the large time steps of implicit schemes are realized. The solution is obtained on an algebraically generated C-grid. The code has been used for hover calculations in subsonic flow, in order to compare with existing pressure measurements.

During the current reporting period, the development of the Euler solver continued. The finite-difference method was coupled with a prescribed wake method. The parameters for the presented wake were developed by R.B.Gray. The Euler code did properly produce reduced lift distribution because of the effect of the wake.

The HOVER code, developed by Analytical Methods Inc., was obtained and is now operational on the Georgia Tech CYBER 855. Its results were used to compare with calculations from the Euler wake. The Euler code has been transferred to the University of Georgia's CYBER 205 supercomputer and arrangements are being made to obtain computer time. The Georgia Tech CYBER obtained a virtual environment operating system and calculations were performed that require approximately 750,000 words of memory.

This research effort is presented in the paper entitled "Solution of the Unsteady Euler Equations for Fixed and Rotary Wing Configurations", AIAA Paper 85-0120.

Task 4. Studies of Unsteady Rotor Aerodynamics
J.C. Wu, N.L. Sankar & C. Wang

The purpose of this task is the establishment of a comprehensive understanding of the physical mechanisms associated with the generation of unsteady aerodynamic forces acting on rotors in forward flight.

During this reporting period, work continued on the refinement of two-dimensional, compressible and incompressible Navier-Stokes solvers that can analyze unsteady viscous flow problems such as turbulent dynamic stall. The compressible Navier Stokes solver was modified to accept external disturbances such as random atmospheric gusts and passing vortices from a previous blade. The blade-vortex interaction capability was exercised by solving a number of test cases recently considered at the US ARO sponsored Workshop on Blade-Vortex Interaction. The results of the modified code were presented at the above workshop, and it compared favorably with other works. Two helicopter manufacturers (Hughes Helicopters, Inc. and Sikorsky Aircraft, Division of United Technologies) received magnetic tape copies of the above code and have begun to use it in their work.

The compressible Navier-Stokes solver was also used to analyze a deep dynamic stall problem. The predictions of this solver compare favorably with the experimental data in NASA TM 84-245. These results will be presented in an AIAA paper in January 1985.

A viscous theory of aerodynamic forces and moments, previously reported, was also used to study the blade-vortex interaction problem, and the results of this study were also presented at the ARO workshop. A parametric study of the blade-vortex interaction problem has been carried out using this theory. A zonal procedure for computing unsteady viscous flows, previously reported, is used in the study of the blade-vortex interaction problem for incompressible flow cases.

Work has been initiated in the use of the viscous theory of aerodynamics and the zonal procedure in studying various cases of the dynamic stall problem.

Task 5. Studies of Airframe Flow Field in Forward Flight

J.E. Hubbartt, H.M. McMahon, N. Komerath
E.V. Horowitz, A. Brand, D. Mavris, P. Oliver,
D. Morris and S. Loui

The long term objective of this task is the development and validation of a reliable technique for predicting the coupling between rotor and airframe aerodynamics. The short term goals are to provide a data base for developing and assessing analytical models, to assess existing analytical models, and to investigate the flow features important in rotor-airframe aerodynamics.

The rotor shaft for the Forward Flight Facility has been modified to incorporate a new trigger assembly and a set of slip rings. The shaft has been installed in the 7x9 foot wind tunnel and an extensive series of tests to develop a data base for the cylindrical fuselage model is now underway.

A second rotor hub has been designed and built. This hub is identical to the existing hub except that it is fitted with two small load cells for the measurement of rotor thrust. Static calibrations of the hub have proven the concept, and thrust measurements are scheduled for Spring 1985. In addition, two new smoke wands have been designed and built and will be used for flow visualization and for seeding the wind tunnel flow during LDV measurements. The wind tunnel probe actuator has been modified and is ready for use, two additional microphones have been purchased and installed in the cylindrical model to speed up the measurement of unsteady surface pressures, and an evaluation of wind tunnel wall corrections is underway using methods in the literature.

Regarding the effort in analysis, program VSAERO has been obtained from NASA Ames and has been run and checked out on the Georgia Tech CYBER 855 computer. The results from the Freeman code (NASA Langley) is running and the wake-model portion is being compared with those from other prediction techniques. In addition, a new program to enable user-friendly input to VSAERO is being written.

II. Structures

Task 1. Structural Dynamic System Identification

S.V. Hanagud, J.I. Craig, M. Meyyappa,
Y. Cheng, C. Grimmell, M. Obal, & D. Stuber

The purpose of this task is to develop an approach to advance the state of the art in airframe structural dynamic modeling. Development of applicable system identification techniques - the mathemetical model of the system of interest - and improved physical models are the basis for this research.

In this phase of the investigation, applications of structural dynamic system identification techniques to rotorcraft design modification have been explored. In particular, as a result of the investigation, improvements over the present state of the art have been illustrated. At present, most of the structural dynamic design modifications are being performed by the use of analytical finite element modeling techniques. Design verifications and testing are usually accomplished by tests on the full scale rotorcraft with and without modifications. In such a design modification process, the responsibility primarily lies on analytical modeling capability. In this work, use of structural dynamic system identification techniques and scale models that complement the analytical modeling capability of a rotorcraft has been illustrated by considering a specific example. This example is to consider the additions and modifications to the store carrying capability of a rotorcraft. A paper in this field was presented at the Tenth European Rotorcraft Forum. At present, illustrations in other fields of rotorcraft are being explored.

The inclusion of general damping matrices in structural dynamic models are important in evaluating aerodynamic forces, control of vibrations and evaluation of dynamic response of rotor blades and fuselages. A method for identification of structural dynamic systems with linear general damping matrices was developed during the past year. The method was efficient for systems with small degrees of freedom. At present the method is being generalized to consider a large number of degrees of freedom.

Structural dynamic optimization of helicopter structures is usually based on analytical models obtained from finite element modeling techniques. These analytical models usually do not accurately represent the observed experimental results. Therefore, the optimization of the structural dynamics characteristics may be based on inaccurate analytical models. A utilization of helicopter structural dynamic system identification in these problems is under investigation.

A structural dynamically representative physical scale model is being developed for a tail boom acquired from the US Army Aviation Center, Ft. Rucker, AL. Preliminary testing of the full scale tail boom is now in progress.

Application of structural dynamic testing and identification techniques to accurately determine the dynamic force of helicopter structures is underway.

Task 2. Crashworthy Characteristics of Composite Rotorcraft Structures
S.V. Hanagud, S. Chandrashekara, & P. Sriram

The objective of this task is to conduct basic research to develop improved techniques and procedure for designing crashworthy composite structures for rotorcraft. This objective includes the development of testing techniques and optimization of the crashworthy designs under the constraints of weight restrictions, cost and performance requirements.

A finite element formulation for the study of static postbuckling behavior of composite sandwich plates has been completed. The resulting formulation is a nonlinear incremental formulation based on a total Lagrangian approach. When the formulation was utilized to solve static post buckling problems, it was found that usual iteration procedures such as a modified Newton-Raphson procedure were ineffective and very slow. A constrained arc length iteration procedure has been used to provide comnputational efficiency. Results for specific cases have been obtained. A paper in this field will be presented at the First International Conference of Rotorcraft Basic Research, Research Triangle Park, NC.

Several tests have been conducted to study the effect of aspect ratio on the energy absorption of kevlar sandwich plates.

Dynamic behavior of buckled beams with lateral excitation is being studied to investigate the practical behavior of these structures during a crash sequence.

A special session has been organized for the 41st American Helicopter Society Forum, Dallas, TX, on the crashworthy design of rotorcraft. Drs. Hanagud and Schrage are session moderators with three papers accepted from industry, two from government laboratories and one from a university source.

Task 3. Concepts for Stability Critical Airframe Structures
A.D. Reddy, L.W. Rehfield & A. Valisetty

This task is concerned with crippling and postcrippling behavior of thin walled graphite/epoxy composite airframe members in axial compression. The main objectives are to i) generate an experimental data base on the crippling and postcrippling behavior, ii) develop simple analytical methods to predict these behavior, and iii) provide better insight into the failure processes for this type of structure.

Five types of I-section specimens were produced by Sikorsky Aircraft with (0, +90, 0,+90), (+45, 0, +90, -45), (0, +45, +90), and-(+45, 0, -45) layups from C3000 woven graphite cloth in a 5225 epoxy resin. These represent some of the common layups used in the aircraft industry. Initial sizing of these specimens was done by using a NASTRAN program.

The specimens were compressively loaded (one of each) with the lateral displacement of the web and flange and the overall end shortening monitored with increasing load. Local crippling of the flange and web were assessed nondestructively by a stiffness plotting method. After obtaining consistent estimates of the crippling loads, the specimen was loaded into the postcrippling regime. The end shortening data from this run was utilized to obtain the initial postcrippled stiffness of the specimen. Final test on the specimen was to failure where the failure processes were studied. The failed specimens were next processed to generate specimens for material property characterization. A short I-section compression specimen was prepared and tested to obtain the ultimate compressive strength and a laminated beam was cut out and bend tested to determine the extensional modulus of the material.

A summary of the experimental findings is as follows:

a) The web and the flange crippling loads are close to one another. This conforms to the initial design.

b) The ratio of the failure load of the specimen to the crippling load ranges from 1.02 to 1.74. This suggests a postcrippling load range for some specimen types.

c) The strain on the flange close to the failure site from the postcrippled failure test was observed to be 8881 in/in. This is comparable to the compressive failure strain of 7777 in/in measured on the web in the ultimate compressive strength test. This suggests that a correspondence might exist between the two tests.

d) The experimental crippling load data compares well with NASTRAN predictions when corrected for the difference in modulus obtained from the bend tests.

In addition to the experiments, simple analytical methods are under development for use in design and synthesis of airframe structural systems. These methods are intended to provide efficient, reliable estimates for the preliminary design phase where overall dimensions and ply layups are established. A key issue is the understanding and prediction of the interaction of connected thin walled composite elements. The common interfaces and connections serve to impose boundary conditions or edge fixity conditions which must be appropriately modeled for analysis purposes. Currently, limiting cases of fixity have been analyzed and compared with experimentally deduced results. The data suggest that the web-flange interface behaves very much like a clamped (fixed) edge.

Task 4. Composite Rotor Blade Modeling
L. W. Rehfield

The theory for composite rotor blades that was begun under grants from the Army Aeromechanics Laboratory and the Army Structures Laboratory has been completed. The results are extremely interesting and suggest that elastic tailoring offers considerable potential. A demonstration example study has been conducted which illustrates the magnitude of control the designer may exercise by choosing ply layup and orientation.

A new, important side study conducted under the present task shows that torsion-related warping can have a pronounced effect on the response of composite rotor blades. This is a substantial departure from classical behavior and a new, significant finding. This matter is being pursued vigorously.

III. Aeroelasticity

Task 1. Helicopter Vibration Suppression Techniques
G.A. Pierce, V. Anand, V.R.P. Jonnalagadda, & D.J. Taylor

This program is intended to develop and validate a comprehensive vibratory loads analysis for the evaluation of vibration suppression techniques. The loads analysis will be applicable to nonuniform multi-bladed systems with teetering, articulated, hingeless or bearingless hub constraints. Special emphasis will be placed on blade structural dynamics, hub and mast dynamics, and unsteady blade aerodynamics. The vibration suppression techniques to be considered will include higher harmonic control, blade mounted absorbers, hub mounted absorbers, and aeroelastic tailoring.

This task has resulted in the successful formulation of a comprehensive non-linear set of rotor blade equations in forward nonlinear set of rotor blade equations in forward flight using Hamilton's principle. In the formulation, the torsional variable is defined as a physical angle and the transformation matrix relating the blade undeformed and deformed coordinate systems is derived without making use of Euler-angles. Such a formulation eliminates use of a rotational sequence and for the definition of the torsional variable, the resulting transformation matrix is unique. The blade equations thus derived are extended to include the effect of hub mobility. A stability analysis for a uniform rotor blade in hovering flight will be carried out using the present formulation and the results will be compared with those presented in NASA TN D-8192. An operational computer program will be developed to simulate the blade response using the formulations of blade equations.

FACILITIES/EQUIPMENT

Laser Doppler Velocimeter (LDV) Data Acquisition System
N.M. Komerath, R.B. Gray, J.E. Hubbartt, & H.M. McMahon

The four-beam, two color Laser Doppler Velocimeter (LDV) consists of a five-watt Argon Ion Laser, modular optics, a three axis traversing system, and two counter type signal processors directly interfaced into the memory of a dedicated HP 1000 computer system. Two orthogonal components of flow velocity can be measured simultaneously and nonintrusively, with a spatial resolution of 0.1 millimeters from a distance of over 2200 mm. Frequency shifting on both channels enables measurement of the velocity vector in recirculating flows and a Field Stop system enables measurement close to solid surfaces.

The LDV is transportable and has successfully aided data acquisition in the Static Thrust Facility and the Forward Flight Facility. During this reporting period, the LDV was transported from the nine foot Static Thrust Facility to the seven by nine foot wind tunnel and was used to demonstrate the feasability of measuring rotor-synchronized velocities in the Forward Flight Facility. The results were very encouraging, and seeding with smoke proved to be convenient and satisfactory. Following these initial tests, the LDV was transported back to the Static Thrust Facility where it is being used routinely in experiments under Aerodynamics Task 1. Two papers describing the data obtained thus far with the LDV have been submitted for presentation.

II. Nine-Foot Static Thrust Facility
R.B. Gray

The facility was designed to provide a laboratory-controlled environment for testing model helicopter rotors up to 4.5 feet in diameter in hovering flight. The LDV system described above is being used for data acquisition for Aerodynamics Task 1. The facility has also been used for Aerodynamics Task 2. The updating of this facility was to include the purchase of a modern data acquisition system and factory reconditioning of the mercury slipring assembly. Neither item has been a pressing matter. The reconditioning of the sliprings has been delayed to permit the testing to continue. The data acquisition system was originally scheduled for the third year.

During this reporting period the plexiglas windows through which the LDV operates were removed and replaced with pane glass. This resulted in a significant increase in the number of seeding particles detected in the measuring volume. The particle seeders were upgraded to further increase the seeding density.

Software development is continuing. A data acquisition and analysis program was developed which processes the LDV data more efficiently than in past experiments. A code capable of creating a variety of crossplots from LDV derived data has been developed and is in operation to provide aid with data interpretation. The result of increased seeding and analysis capability has been a substantial increase in the quantity of measurements possible.

In a separate effort, attempts are underway to evaluate the unsteadiness in the flow field within the nine-foot hover facility.

III. Structural Dynamic System Identification Facility

S.V. Hanagud & J.I. Craig

This laboratory is developed to measure, record, process, and analyze structural dynamic data for laboratory model tests and field tests. The multichannel time series and structural dynamic analyzer allows acquisition of data from one to eight channels simultaneously with the capability to expand to sixteen. The analysis software may run on the dedicated computer system or is portable to another system.

During this reporting period the GENRAD analyzer has been updated by acquiring software DATM and MODAL PLUS 8.1. A printer and plotter for the system have been acquired.

IV. Transient Dynamic Stress Analysis Facility

S.V. Hanagud & J.I. Craig

This facility is for the study of the dynamic behavior of structural components and assemblies under typical crash-induced loading situations for helicopters. The design of the facility involves a drop-test fixture for producing dynamic compressive loading of various metallic and composite test articles. A variety of waveform recorders acquire data during investigation of crashworthy characteristics of rotorcraft structures, particularly composite structures.

During this reporting period, a "LeCroy System" has been acquired and is operational. This is used for data acquisition in dynamic buckling tests. This system is a waveform recorder in a CAMAC System with 32 MHz sample rate.

A HP 9817 computer has been ordered. This will control the LeCroy sysem and provide analysis and graphics presentation.

V. Seven-by-Nine Foot Forward Flight Facility

J.J. Harper, J.E. Hubbartt, H.M. McMahon, & S.S. Kleinhaus

The original nine-foot low speed wind tunnel has been converted to a seven-by-nine foot test section forward flight facility. The design and installation of a powered model rotor system, fairings, floor, ceiling and honeycomb complete the conversion. The rotor system is lowered from the test section ceiling and fuselage models are mounted on a force balance sting. The Laser Doppler Velocimeter, a dedicated computer system and a modern force balance provide for data acquisition.

A honeycomb has been installed in the settling chamber just upstream of the test section. This honeycomb has eliminated the streamwise vortex which had been observed in the test section. A survey at two streamwise locations in the test section showed that the improved flow has an inclination of 1/4 degree or less over the range of freestream velocities used in the Forward Flight Facility. The wind tunnel now is ready for use for measuring flow velocities and pressures. The wind tunnel balance will be calibrated later.

VI. Aeroelastic Rotor Test Facility

G.A. Pierce, S.S. Kleinhaus, M. Hashemi-Kia & V.M. Kaladi

The primary purpose of this facility is to permit large-scale testing of rotor systems. Such tests are concerned with steady and unsteady aerodynamic phenomena, structural dynamic response behavior, and evaluation of vibration suppression techniques. Model rotor systems of up to ten - foot diameter can be accommodated. The initial test program will include excited aeroelastic models which have been Froude scaled in support of Aeroelasticity Research Task 1 on helicopter vibration suppression.

The facility consists of a horizontal cylindrical shroud of sixteen foot diameter and 20 foot length. The shroud is constructed of honeycomb to eliminate the vorticity of the recirculating flow. The downstream end contains a honeycomb partition with a wake inductor concentric with the longitudinal axis to permit the free passage of the rotor wakes. A horizontal shaft is powered by an external variable speed drive with a maximum speed capability of 2000 rpm. A fifty-two-channel slip-ring assembly is installed for transmission of data signals.

Immediately adjacent to the facility is a control room for remote operation of the drive mechanism and data conditioning and analysis. In addition to the operators control panel, the control room contains instrumentation power supplies, amplifiers, recorders, a dedicated computer system, and other miscellaneous signal conditioning equipment.

During this reporting period, an air excitation system has been developed and is in operation. It consists of four nozzles mounted upstream of the blades which may be operated individually or simultaneously. The air jet from the nozzles produce excitational forces on the rotating blades. Air is fed to the nozzles by an 1000 cubic foot tank charged by a reciprocating compressor up to a maximum pressure of 125 psi.

Layout and design of the hub mounted signal amplifiers has been completed and other work has focused on the design of hardware for future tests, most notably the swashplate assembly necessary to perform vibration suppression research using higher harmonic control techniques.

UPDATED AND NEW COURSE DEVELOPMENT

The status of the courses to be updated and the new courses to be developed are shown in Table 1. The updating of courses has been completed. Those new courses that were developed during earlier reporting periods or have a comment in the Remarks column that they have already been taught have been reported on in the corresponding progress report for that period. The status of the remaining courses is given below.

Aerodynamics of the Helicopter III
R.B. Gray

This course is an introduction to vortex wake analyses of both classical and finite bladed rotors, for both hovering and forward flight conditions. Initial offering of this course was Summer 1984. Two PhD students and six M.S. students took the course for credit.

Rotorcraft Design I
D.P. Schrage

This four credit introductory design course begins with V/STOL technology concepts and test experiences with experimental rotorcraft. It emphasizes concept formulation, technology assessment and graphical methods of preliminary design. Five member design teams complete projects in response to an annual Request for Proposal for the American Helicopter Society/Boeing Vertol Company Rotorcraft Design Competition.

Rotorcraft Design II
D.P. Schrage

This four credit course is a continuation of Rotorcraft Design I and introduces the student to many of the computer based rotorcraft sizing and analysis codes now in use in the helicopter industry. Primary focus is the detailed design of a proposal to the national AHS/Boeing Vertol Company Rotorcraft Design Competition. This course was first offered in Summer 1984.

Compressible Flow
N.L. Sankar & S.G. Lekoudis

This three credit course introduces the student to the principles of Computational Fluid Dynamics (CFD) using model elliptic equations. This is expressed in airfoil design for rotor applications. Fifteen students enrolled in this course for credit during Summer 1984.

VISITS/COMMUNICATIONS

1. R.B.Gray

Planning Meeting, International Conference on Rotorcraft Basic Research, Washington, DC, November 27, 1984

The purpose of this travel was to attend a planning meeting for the First International Conference on Rotorcraft Basic Research. Persons contacted include Dr. Robert E. Singleton, Dr. William F. White, Dr. G. Larry Roderick, Dr. C.E. Hammond, and Dr. Albert Gessow.

2. S.V. Hanagud

US Army Aviation Safety Center, Ft. Rucker, AL, November 26, 1984

The purpose of this visit was to meet with Mr. Jim Hicks of the USA Aviation Safety Center to discuss an upcoming special session at the 1985 American Helicopter Society Forum for Crashworthy Design of Future Rotorcraft.

3. S.G. Lekoudis

Bell Helicopter Textron, Ft. Worth, TX, September 21, 1984

This visit was conducted to discuss possibilities of Dr. Lekoudis serving as a six month, part-time employee for Bell. Mr. Warren Young, Director of Research Projects, and Mr. Tom Wood and Mr. Jim Nakahora of the Handling Qualities Group were present. The discussions centered on fuselage aerodynamic questions.

4. D.P. Schrage

National Rotorcraft Specialist Meeting on Advanced Cockpit Design, Dallas, TX, October 3-4, 1984

The purpose of this trip was to discuss opportunities for cooperative research in aircrew and aircraft integration and a proposed multidiscipline curriculum in this area at Georgia Tech. Considerable interest was expressed by NASA, Army, Air Force, and industry representatives. Mr. Dick Henschel, Technical Chairman of the Specialists Meeting, was extremely helpful and other discussions were accomplished with representatives from government and industry.

NASA Ames, Moffett Field, CA, October 17, 1984

During this visit, discussions for a potential joint research program in the area of aircrew and aircraft integration and the graduate co-op program were conducted. Dr. Irv Statler, U.S. Army, Dr. John Zuk and Mr. Greg Condon were contacted. The NASA and Army representatives were and are enthusiastic about working with Georgia Tech in aircrew-aircraft integration. NASA will be sending some material on joint research opportunities. Information obtained on this trip was used in response to a request to include Aerospace Avionics Research in the Georgia Research Consortium. The Consotium is a research management agency of the State of Georgia developed to encourage high technology research to locate in the state.

US Army Aviation Briefing for Industry, Ft. Rucker, AL, November 14-15, 1984

The purpose of this visit was to attend the US Army Aviation Industry Update at Ft. Rucker, Alabama. The presentations provided an update on Army Aviation technology and potential opportunities for university involvement in the US rotorcraft technology base. A number of discussions during this visit focused on university support by corporations under an IR&D arrangement. COL Clark Burnett, Director of Combat Developments, chaired the conference.

Modeling, Simulation and Gaming of Warfare Workshop, Callaway Gardens, GA, December 3, 1984

This travel was performed to present a paper entitled "Modeling, Simulation and Gaming (MSG) of Warfare in Support of Army Aviation" at the 1984 Workshop. Discussions focused on the cross-disciplinary nature of rotorcraft technology and the need for rotory wing engineers to interact with other aligned disciplines. Workshop Chairman was Dr. L.G. Callahan, Professor of Industrial and Systems Engineering, Georgia Institute of Technology.

Peer Review of the Second Generation Comprehensive Helicopter Analysis Program (2GCHAS) Technology Complex (TC) Request for Proposal (RFP), NASA Ames Research Center, Moffett Field, CA December 13-14, 1984

The purpose of this trip was to represent Georgia Tech and the Center of Excellence at this review. University participation in the development of 2GCHAS was explored. It appears that universities will have to work in a sub-contractor role to industry to participate in the program. In a related effort, topics for helicopter stability and control research were explored. NASA has several forthcoming simulation experiments in which student participation is desired. Further efforts with NASA will quantify the student involvement. Persons contacted include Dr. Robert A. Ormiston, 2GCHAS Project Manager, Mr. David L. Key , Mr. Edwin W. Aiken and other government, industry and university participants.

5. L.W. Rehfield

NASA/DoD Composites Structures Technology Conference, Seattle, WA, August 13-15, 1984

The conference provided an in-depth review of the NASA ACEE composite structures programs with Boeing, McDonnell-Douglas Aircraft and Lockheed. Presentations on selected DoD programs were given, basically in areas where technology supported the NASA efforts. Examples are the USAF-Boeing-Northrop Damage Tolerance Program, the US Army Advanced Airframe Composite Airframe Program, and the US Navy Joint Services Vertical Lift Program (JVX). Overall [illegible] were that: 1) there is a growing confidence among [illegible] builders, but they are far behind fighter builders. The [illegible] industry is proposing bold initiatives for JVX and LHX, but [illegible] depth of manpower and experience with primary structure in [illegible]; 2) FAA certification of composites has retarded progress; 3) [illegible] is clearly in a leadership position engineering-wise; 4) The initiative is in the hands of general aviation, with operating [illegible] of some of the recent designs approaching that of ground transportation.

6. J.C. Wu

Vortex-Blade Interaction Conference, NASA Ames Research Center, Moffett Field, CA, October 31, 1984

The purpose of this trip was to present the invited paper entitled "Computational and Theoretical Studies of Blade-Vortex Interaction Aerodynamics using Zonal Procedures". Further interaction with colleagues and other attendees was also accomplished.

7. S.S. Kleinhaus

USA AVSCOM RTL, NASA Langley Research Center, Structures Laboratory, August 22-23, 1984

The objective of this trip was to discuss the design and operation of the set of model rotor blades being donated to Georgia Tech, obtain input on hub design, and to discuss the design of several accessories for the Aeroelastic Rotor Test Facility. A tour of the V/STOL and transonic dynamics tunnel were of great interest. Persons contacted include Mr. John Wilson, Mr. John Berry, Mr. Arthur Phelps, Mr. John Cline, and Mr. William Yeager.

US Army Aviation Center, Ft. Rucker, AL, August 12, 1984

The purpose of this trip was to examine the crashed fuselages of two TH-55 training helicopters released to Georgia Tech. The wreckage was deemed unusable. The intent was to salvage the control system to develop a training mock-up to illustrate how lateral stick movements are translated to the rotating reference frame of the rotor system.

US Army Aviation Center, Ft. Rucker, AL, September 27, 1984

This trip was to the Ft. Rucker Property Disposal Office to meet with Mr. Carlson Long, Georgia State Agency for Surplus, and screen for discarded items that would be of benefit to the Structural Dynamic System Identification Facility. A meeting with Mr. Fred Mathews, Aviation Logistics Maintenance Division, followed on the subject of training manuals for the UH-1 and TH-55 aircraft.

8. S.A. Meyer

USA AVSCOM RTL, NASA Langley Research Center, Structures Laboratory, July 12, 1984

This visit with Mr. Richard Long and Dr. Larry Roderick was to discuss the US Army's continuing role in support of the Centers of Excellence.

American Helicopter Society, Alexandria, VA, July 13, 1984

Mr. Walter Bacak, Editor of Vertiflite magazine, proposed a bimonthly column on university research in the rotory wing field and its impact on the rotorcraft community.

University of Maryland, College Park, MD, July 13, 1984

This visit was to become familiar with the University of Maryland Center of Excellence. Dr. Inderjit Chopra provided an excellent overview of the Maryland program and a tour of the test facilities. Areas of common interest and the successful continuation of the Centers program was discussed.

US Army Aviation Center, Ft. Rucker, AL, August 12, 1984

The purpose of this trip was to examine two crashed fuselages of TH-55 training helicopters that were released to Georgia Tech by the US Army. The wreckage was deemed unusable for the purpose of developing a control system mock-up to illustrate to students the translation of lateral stick movements to the rotating frame of reference of the rotor system.

Persons contacted include Mr. Jim Smith and Mr. Ford Mathews of the Aviation Logistics Maintenance Division, Mr. Jim Craig of the Aviation Museum and Mr. Joe Stroud of the Ozark Aviation Technical School, Ozark, AL.

Aircraft Systems and Technology Conference, October 18-19, 1984 Los Angeles, CA

The purpose of this travel was to represent the Center at the Aircraft Systems and Technology Conference. DoD representation was strong and presentations concerning advanced rotorcraft highlighted the proceedings. Persons contacted include Mr. Frank McGuire, Editor of Helicopter News, Mr. Evan Fradenburg, Sikorsky Aircraft, and Mr. David Hubble, USA AVSCOM Heavy Lift Helicopter Concept Manager.

Hughes Helicopters, Inc., Culver City, CA, October 19, 1984

This visit was to discuss potential Georgia Tech research coordination with Hughes Helicopters, Inc. Proposals were presented by Dr. Daniel Schrage and myself on behalf of faculty of the Center of Excellence in Aerodynamics, Structures, Aeroelasticity and Flight Mechanics and Controls. Dr. E. Roberts Wood, Mr. Dev Banerjee and Mr. Ram Janikaram were contacted. The trip was successful in that 3 joint research efforts were initiated that included support for two graduate cooperative students in computational fluid dynamics and advanced flight controls.

Army Aviation Briefing for Industry, Ft. Rucker, AL, November 14,15, 1984

This visit was to represent the Center of Excellence at the US Army Aviation Industry update. Presentations were initially given by US Army Aviation Center personnel outlining user need and the TRADOC perspective. USA AVSCOM personnel continued the conference by presenting a rotorcraft technology assessment and overview of the Family of Light Helicopters (LHX) program.

Bell Helicopter Textron, Ft. Worth, TX, November 26, 1984

This trip was to meet with Bell engineers and coordinate potential areas of common interest with the Georgia Tech Center of Excellence. Mr. Sathy Viswanathan and Mr. Viswanath Tata were extremely helpful in organizing the donation of model rotor hubs and blades during this time. Other persons contacted include Mr. Karl Mathews and Mr. Jon Rogers.

9. N.L. Sankar

ARO Vortex Blade Interaction Workshop, NASA Ames Research Center Moffett Field, CA, October 31, 1984

The purpose of this trip was to present the invited paper entitled "Computational and Theoretical Studies of Blade Vortex Aerodynamics using Zonal Procedures". Further interaction with collegues and other attendees was also accomplished.

SIGNIFICANT EVENTS

Donations

US Army, Corpus Christi Depot Engineering Support Section, Corpus Christi, TX, October 10, 1984

Mr. Robert Ladner and Mr. Advaney of Corpus Christi, TX were extremely helpful in locating and refurbishing a rotating control assembly of a UH-1 helicopter. The swashplate assembly is initially in use as an engineering exhibit and serves as a design aid for the cyclic pitch control of the Aeroelastic Rotor Test Facility.

US Army, Property Disposal Office, Ft. Rucker, AL

Components for an entire UH-1H tail boom and tail rotor system are now being assembled in the Structural Dynamic System Identification Facility. The acquisition of the majority of these parts resulted from the efforts of Mrs. Culpepper, Mrs. Tharpe and Ms. Diane Singleton of the Ft. Rucker PDO, and Mr. Jim Smith and Mr. Ford Mathews of the Aviation Maintenance Logistics Division, Ft, Rucker, AL.

Two Bell Model 206 swashplate assemblies and two pilot seat frames were recovered from Property Disposal.

US Army Research and Technology Laboratories (USA AVSCOM) Structures Laboratory, NASA Langley Research Center October 15, 1984

Mr. William Pleasants greatly aided the Georgia Tech Center of Excellence with his efforts in sending the HOVER analysis code. The code will be utilized in support of the computational fluid dynamics tasks.

Bell Helicopter Textron, Ft. Worth, TX, November 26, 1984

Mr. Sathy Viswnathan, Director of Technology, Bell Helicopter Textron - Canada, and Mr. Viswanath Tata were instrumental in the donation of the following equipment to the Georgia Tech Center of Excellence:

a) Model 654 four-bladed rotor hub

b) Model 640 two-bladed rotor hub

c) Model 206 two-bladed rotor hub (2)

d) Model 206 tail rotor hub with blades

e) Model 206 transmission assembly

f) Various graphite and component helicopter parts

Most of the above equipment will be utilized in the construction of a Bell Model 206 dynamic components mock-up, similar in design to the US Army maintenance training devices and control system demonstrators.

1984 American Helicopter Society/Boeing Vertol Rotorcraft Design Competition "Combat Search and Rescue Helicopter"

Dr. Dániel P. Schrage served as Faculty Advisor for two teams of student engineers that placed Second and Third in the 1984 competition. The Second Place team was comprised of Thomas Thompson, Warren Carpenter, MAJ William Hatch (USA), Dana J. Taylor, and Neil Weston. The Third Place team was comprised of Prasad Jonnalagadda, Albert Brand, N.S. Abhyankar, Ashish Sareen, and Edward Parleman.

Short Course in Advanced Rotorcraft Design and Technology Dr. Daniel P. Schrage, November 1-10, 1984

Dr. Schrage presented a series of short courses in Advance Rotorcraft Design and Technology in London, England, Paris, France and Frankfurt, Germany.

Flight Safety International, October 1, 1984

The Center hosted the management and sales directors of Flight Safety International, an international firm specializing in flight training and simulator development. Dr. Daniel Schrage and Mr. Stephen Meyer described the School's activities, an overview of current helicopter technology, and the unique rotary wing engineering research facilities available at Georgia Tech.

Computer Programs

The following helicopter computer codes are operational and are being used in various aspects of the Center's activities.

HESCOMP/VASCOMP	NASA/Boeing Vertol	Rotorcraft Sizing and Performance
C81	ARMY/Bell Helicopter	Comprehensive Helicopter Analysis

FLYRT	Hughes Helicopters	Flight Mechanics
DNAMO5	ARMY/Bell Helicopter	Vibration Analysis
SSP1/SSP2	ARMY	Single Rotor Helo Sizing and Performance
GTR	Bell Helicopter	Tilt Rotor Flight Mechanics Program
HOVER	ARMY Structures Lab	CFD Hover Analysis
HESS/FREEMAN	NASA/USARTL Langley	Rotor-Airframe Potential Flow
VSAERO	NASA Ames	Coupled potential-boundary layer analysis
DYSCO	Kaman Aerospace	DYnamic System COupler code

Presentations

The following seminars were presented and well received at the Georgia Tech Center of Excellence:

"Application of the Advancing Blade Concept to the Emergency Medical Service Helicopter Role", Mr. Larry S. Levine, Sikorsky Aircraft Divison, United Technologies, July 5, 1984

"The V/STOL Technology Challenge", Mr. Kaydon Stanzione, Boeing Vertol Company, July 17, 1984

"Vibration Suppression Using Higher Harmonic Control", Dr. E. Robert Wood, Hughes Helicopters, Inc., July 19, 1984

"Minimum Required Data Input for Helicopter Trim Using C-81 and Optimization Techniques", Dr. Richard Bennett, Bell Helicopter Textron, July 26, 1984

"Aerodynamic Measurements about a Rotating Propellor with a Laser Velocimeter", J. Lepicovsky, Lockheed-Georgia, August 3, 1984

"Conceptual Designs of Rotorcraft to meet the Public Service Helicopter (PSH) Requirements", AE 8155, Team A and B, August 21, 1984

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LOCAL CRIPPLING OF THIN WALLED COMPOSITE STRUCTURES UNDER AXIAL COMPRESSION

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Abstract

Thin walled members are part of the primary structure which constitute a significant portion of the total airframe structural weight. The ability to design them better depends on the availability of reliable fiber reinforced composite thin walled structures which are prone to local crippling but has been limited. There is a need for a larger data base and greater understanding of local crippling behavior of these design procedure and test methodology. The amount of work done on structural members, especially with complex or multiple local modes, has been small.

In view of the above observations, this effort was undertaken to investigate the local crippling behavior of thin walled graphite/epoxy I-section beams under axial compression. The main objectives are to (1) generate an experimental data base on the behavior of these members, (2) develop simple analytical methods to predict the local buckling loads, and (3) provide better insight into the failure processes for these type of structures.

A STUDY OF THE STATIC POST BUCKLING BEHAVIOR OF COMPOSITE SANDWICH PLATES

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One of the requirements of a crashworthy design of a rotorcraft structure is to absorb the energy of a survivable crash outside the occupant space. In order to meet this requirement in a composite rotorcraft, innovative concepts such as composite sandwiches with crush zones, subfloors with corrugated webs and foam filled cylinders have been proposed. In many of these structural concepts the mechanism of energy absorption can be explained by studying their static post buckling behavior and dynamic buckling characteristics. Such a study will assist in improving the structural concepts for crashworthy design and developing detailed design procedures for selected structures. In this paper, a study of the static post buckling behavior of composite sandwich plates have been discussed. As is needed in crashworthy design, a finite deformation analysis has been performed and the results have been compared with test results.

IDENTIFICATION OF SYSTEMS WITH GENERAL DAMPING MATRICES

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In many cases, analytically calculated dynamic responses and dynamic characteristics of helicoper structures do not agree with the experimentally measured quantities. One way of improving the analytical model is by use of structural dynamic system identification techniques. Even though the subject of system identification as applied to the field of structural dynamics is relatively new, there has been a considerable amount ot development in this field. Most of the developments are concerned with linear structural dynamic systems with finite degrees of freedom. Such systems are usually represented by mass stiffness and damping matrices whose order is equal to the number of degrees of freedom chosen in modeling the physical system. An identification problem of such a system is to determine the system matrices for the measured dynamic behavior of these systems. Although a substantial number of techniques have been developed to identify undamped or proportionally damped matrices, and the measured modes are usually complex, techniques that can identify structural dynamic systems with general damping matrices are very few.

Recently a different approach to the problem has been developed by the authors of this paper. This approach is based on the assumption that either some or all the elements of the mass matrix are known. It is also assumed that the complex eigenvalues and the complex eigenvectors have been measured. The parameters of the remaining elements of the mass, stiffness and damping matrices are then determined by minimizing the Eucledean norm of a matrix that assures the satisfaction of the eigenvalue problem and the appropriate orthogonality conditions. The symmetry of the matrices has been imposed as a constraint to the eigenvalue problem.

In this paper the assumption that some elements of the mass matrix be known exactly has been removed. A method for identifying structural dynamic systems with general linear damping matrices has been developed by assuming that the mass matrix is only known approximately. It is also assumed that the stiffness matrix is known approximately.

THE PREDICTION OF THE FLOW AROUND BLADE TIPS

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Abstract

This paper has two objectives: a) To review the literature on the subject of calculating the flow around blade tips and b) To present a new method for computing blade tip loads based on the Euler equations.

The capability of predicting flow fields around blade tips is very important because the tip is at the location of the maximum dynamic pressure and contributes significantly to the blade loads. Compressibility effects, a limiting factor in the speed of forward flight, are first experienced at the blade tip. The strong tip vortex modifies the effective angle of attack at inboard blade sections and therefore influences the blade loading inboard. Finally, the presence of unsteady shock waves in forward flight increases the noise generated by the rotor.

In principle, solutions of the (time-averaged) Navier-Stokes equations constitute the most advanced engineering tool for the foreseeable future. However, due to the required computer resources, no attempts have been made to solve the problem in the case of a rotor blade. This is in contrast to the problem of isolated wings which are currently being solved using super-computers. There are two factors that contribute to this complexity. The first is the flow unsteadiness for the case of forward flight and the second is the presence of the wake. The wake stays near the blade and the numerical simulation has to resolve large regions of flow with strong velocity gradients. This process involves significant computer resources.

Because of the above mentioned reasons, alternatives to solving the Navier-Stokes have been sought. These alternatives are primarily solution methods that use inviscid flow theory and distributed singularities (panel method). One can categorize these into two groups: panel methods that use free wakes and methods that use prescribed wakes. Each method has advantages and disadvantages and are discussed in the paper. It should be emphasized that only recently these methods were developed with the idea of predicting the flow details around the blade tip. The amount of literature devoted to the tip flow prediction is only a very small part of the literature devoted to the prediction of blade loads. Around the tip the flow is highly three-dimensional. In hover, the effect of the section of the tip-vortex that exists before the blade trailing edge is large only in the last few percent of the blade span. This paper includes a review of analytical efforts for the case of hover and comparison between theory and experiment.

Because of compressibility effects, the case of forward flight is more difficult to predict. Full unsteady calculations have been done using transonic small disturbance theory and calculations using full potential theory have been done in the quasi-steady form. This paper discusses these efforts in detail. There are difficulties with these methods, however, associated with the incorporation of tip vortices in the calculations. The next level of complexity is encountered in the use of Euler equations. Some justification is warranted for their use because the computer resources required for their solution is large.

For the case of hover, the Euler equations can capture and transport vorticity provided the numerical diffusion is small. Thus the need to place a near tip-vortex is eliminated. The vortex still has to be initiated, however, either from a sharp corner or through the boundary conditions. For the case of forward flight, these equations give the correct behavior and strength of the shocks at the tip which are of importance in predicting the loads, and in examining the noise generation.

The difference in shock location and strength predicted by the Euler equations and the full potntial approach may be significant enough to warrant researching both alternatives. Moreover, any shock/vortex interaction is appropriately computed.

The paper describes in detail the use of a hybrid implicit-explicit numerical solution for solving the three-dimensional Euler equations and its application to the blade tip problem. The computations are accomplished using an algebraic C-grid. The calculation of the wake is performed as follows. The wake geometry of the tip vortex is prescribed and its strength is associated with the blade maximum bound circulation. Velocities due to that vortex are explicitly computed and they constitute inhomogeneous terms in the system of the Euler equations. Details of the method and the numerics are given in the paper. The calculations are, to the authors' knowledge, the first of their kind and demonstrate the feasibility of the approach in predicting the loads for the case of a hovering rotor.

In spite of the fact that "transonic tip" designs have been used and are being used in helicopter blades, there are several outstanding problems in the aerodynamics of blade tips that remain to be solved. The majority can be grouped under viscous effects and effects due to turbulence. This paper discusses methodology used to account for these effects and what may be fruitful approaches for future consideration.

LOCAL CRIPPLING AND POSTCRIPPLING BEHAVIOR OF GRAPHITE/EPOXY THIN WALLED AIRFRAME MEMBERS

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Abstract

The aircraft of the future need airframes lighter in weight than the current ones to meet specific design objectives. Extensive use of composite materials is expected for this reason to produce efficient airframes.

Thin walled members are part of such airframe structures which constitute a significant portion of the total structural weight. Further weight benefits are promised if these elements made of composites are designed to operate in the post-crippled regime. The limited experience in this area has so far prevented full utilization of this concept. Thus, there is a need for a larger database and greater understanding of the local crippling and postcrippling behavior of these structural members.

With the above considerations, this program was undertaken to study the local crippling and postcrippling behavior of thin walled graphite/epoxy I-section beams under axial compression. The main objectives of this program are to i) evaluate the crippling and postcrippling behavior of these structural members, ii) develop analytical methods to predict this behavior, and iii) suggest methods to predict the failure processes for this type of structure.

NUMERICAL SOLUTION OF UNSTEADY VISCOUS FLOW PAST ROTOR SECTIONS

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Abstract

A compressible Navier-Stokes solver has been developed for unsteady airfoil calculations frequently encountered in rotor applications. This procedure solves the unsteady, compressible Navier-Stokes equations on a body-fitted moving coordinate system in strong conservation form using an ADI procedure. This procedure is capable of treating embedded point and distributed vortices without excessive numerical diffusion, and can capture embedded shocks without overshoots. Numerical results are presented for the following cases to establish the usefulness of this procedure: 1) Steady inviscid transonic flow over a NACA 0012 airfoil for a number of Mach numbers and angles of attack, 2) Steady subsonic viscous flow past a NACA 0012 airfoil at 0.3 Mach number and 3 million Reynolds number, 3) Inviscid transonic flow calculations involving vortex-airfoil interaction, and 4) Turbulent dynamic stall calculations for a NACA 0012 airfoil. In all cases presented, the results are compared with experimental and other published data.

SOLUTION OF THE UNSTEADY EULER EQUATIONS FOR FIXED AND ROTOR WING CONFIGURATIONS

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Abstract

A solution procedure is described for the numerical solution of inviscid rotational flow past fixed and rotor wing configurations. This procedure solves the three dimensional Euler equations in a body fitted coordinate system and in strong conservation form. The derivatives along the spanwise direction are lagged by one time step, while all the other terms are treated in a fully implicit manner. This leads to a semi-implicit scheme that requires two block tridiagonal matrix inversions and one residual evaluation per point at every time step. This procedure also requires the flow variables to be stored at only one time level. A number of fixed wing and rotor wing calculations are presented to demonstrate the efficiency and accuracy of this procedure.

UNSTEADY AERODYNAMICS OF AN AIRFOIL ENCOUNTERING A PASSING VORTEX

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Abstract

The problem of vortex airfoil interaction is analyzed using three approaches: a. Incompressible flow calculations using comformal mapping techniques, b. Incompressible viscous flow calculations using the vorticity stream function formulation, c. Compressible inviscid transonic flow calculations using the Euler equations. In the incompressible flow calculations the aerodynamic loads experienced by the airfoil are decomposed into components associated with distinct physical process using a generalized aerodynamic forces and moments theory. Numerical results are presented for a NACA 0012 airfoil at zero angle of attack encountering a vortex of strength -0.20 V c at zero and 0.8 Mach number and for a NACA 64A006 airfoil at a free stream Mach number of .85 and zero angle of attack encountering a vortex of strength -0.2 V c. Results are compared with available theoretical and experimental data.

NUMERICAL SOLUTION OF NAVIER-STOKES PROBLEMS USING INTEGRAL REPRESENTATIONS WITH SERIES EXPANSIONS

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Abstract

Steady state incompressible Navier-Stokes and continuity equations are recast into integral representations for the velocity vector and the vorticity vector using the concept of fundamental solutions. Integrals are dicretized using finite Fourier series approximations. An efficient iterative procedure is established for the numerical solution of internal flow problems in two-dimensions. The iteration loop in this procedure is composed of a kinetic step and a kinematic step. Explicit computations are utilized in each step. Boundary vorticity values required for the kinetic step are determined form constraint equations obtained from the kinematic aspects of the problem expressed in the integral representation form. Several flow problems are studied numerically for various Reynolds numbers. Flow structures are determined from numerical results obtained. A Bachelor's flow model of constant vorticity is verified numerically for high Reynolds number closed streamline flows inside a circle.

COMPUTATIONAL AND THEORETICAL STUDIES OF BLADE-VORTEX INTERACTIONS AERODYANAMICS USING ZONAL PROCEDURES

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Summary

Encounters between lifting surfaces and free passing vortex systems often produce unsteady interactive flowfields in the non-linear domain. Mathematical, computational and experimental difficulties attendant to a rigorous treatment of the encounter problem are great. Many of the essential and unique features of the encounter problem are not well understood today.

During the past two years, the authors have carried out theoretical (non-computational) and computational studies of the encounter problem using zonal procedures, with the goal of establishing an improved understanding of the physical process contributing to the unsteady aerodynamic loads.

A general viscous theory of aerodynamics, previously developed by the present authors, is utilized in the present studies. The theory is a direct consequence of the Navier-Stokes equations and is valid for viscous flows, including those containing massive separation regions. The theory permits the overall unsteady load acting on a lifting surface to be divided into individual components, each associated with a specific flow element present in the flowfield. The theory further shows that only viscous (vortical) elements of the the flow contribute to the unsteady aerodynamic load and that the simple sum of the individual contributions gives the total aerodynamic load even when the interactive flow is in the non-linear domain. Three major contributors to the unsteady aerodynamic load are identified and their relative importance has been assessed using the general theory. These contributors are i) the unsteady boundary layers surrounding an airfoil, ii) the vortical wake shed by the airfoil during the encounter, and iii) the free vortex system passing by the airfoil. Closed form analytical expression has been obtained for unsteady lift and unsteady drag under restricted circumstances.

A numerical method based on the concept of fundamental solutions, also previously developed by the present authors, is utilized in the computational study of the encounter problem. This numerical method permits the boundary layer part of the flow to be computed separately from the detached (recirculating and wake) regions of the flow. As a result, the method offers great computational efficiency and accuracy. Selected numerical and theoretical results are presented here together with a discussion of the several important contributors to the unsteady aerodynamic load.

VELOCITY MEASUREMENTS IN THE NEAR WAKE OF HOVERING ROTOR

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Abstract

Current methods for rotorcraft flow field prediction require knowledge of the characteristics of the flow field in the near wake downstream of the rotor. The near wake presents a challenging measurement and modeling problem, involving steep and rapid fluctuations in velocity gradients, and a complicated system of vortices and vortex sheets.

The objectives of the experiments being conducted at the Georgia Tech Static Thrust Facility are to measure the details of the core structure at the tip vortex of the near wake of a spinning rotor blade, and to validate analytical models for this core and its evolution. Along the way, however, various problems have to be surmounted, and various other characteristics must be established. These intermediate results will form the subject matter of this paper, which will also include some results of direct applicability to currently used techniques for rotorcraft flow field and performance prediction. A section of the paper will also be devoted to description and discussion of the procedures for making these measurements using a Laser Doppler Velocimeter (LDV).

The experiments are conducted using a single bladed untwisted rotor with a NACA 0012 blade section of constant chord 127 mm. and a radius 0.61 meters. The rotor is enclosed in a hover facility with a wake inductor. Provisions are made for measurement of thrust and blade surface pressures. The laser velocimeter is a two-channel, counter-based system with a three-axis optical traverse and a back scatter optics arrangement. Seeding of the flow field is performed using a resonating nozzle that produces clouds of micron sized water droplets without causing undue flow field interference. Data from the velocimeter is synchronized with the rotor blade azimuth and ensemble-averaged to reveal the details of the velocity at a point in the wake as a function of blade position.

The contraction profile of the near wake has been deduced from the LDV data. In the paper, the variation of this profile with rotor operating paramenters will be presented, and compared with models used in current hover prediction codes. This is a source of uncertainty in the simpler, available codes, and hence is of immediate interest.

In measuring velocity using the laser velocimeter, one of the problems is the error caused by particle inertia in regions of high acceleration. This effect is studied by examining the probability of measuring arrival as a function of position in the flow field.

Unsteadiness of the flow field is a frequently occuring problem in attempts to make such measurements in rotor flow fields. This problem will be addressed in the paper using measurements made in both the inflow region as well as the wake. Of special concern are low-frequency fluctuations in the position of the tip vortex.

Comparisons will be presented of the path of the tip vortex as measured by the LDV and computed from simple theories. The velocities induced by the tip vortex in its vicinity will be used to compute the strength of the tip vortex. The suspected occurence of secondary vortices will be discussed using the velocity data.

AERODYNAMIC INTERACTIONS BETWEEN A ROTOR AND AIRFRAME IN FORWARD FLIGHT

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Abstract

The ability to predict aerodynamic interactions between a rotor and airframe is crucial to the design of rotary wing aircraft. The dynamics, performance, acoustics, and handling qualities of such aircraft are significantly influenced by such interactions. Due to the complex nature of the flow field, both prediction and measurement of these interactions pose challenging problems to researchers in aerodynamics.

The aerodynamic interactions between a helicopter rotor and airframe are the subject of a study currently underway at the Georgia Institute of Technology. The objective of this program is the systematic measurement of such interactions between rotors and bodies, and the validation of prediction codes using these measurements. In this paper the flow-field characteristics predicted by currently-used codes will be compared with measurements.

The program of measurements is being conducted in a 7 x 9 foot wind tunnel using a stiff, 2-bladed teetering rotor and a long cylindrical body with a hemispherical nose. The rotor hub is designed to minimize hub effects in the data. Mean and time-resolved pressures are recorded on the body surface. Rotor thrust is measured using load cells. Flow field measurements are conducted using a two-channel Laser Doppler Velocimeter.

Flow field predictions discussed in this paper are primarily made using the Clark and Maskew code developed by Analytical Methods, Inc. for NASA Ames Research Center. The code employs a three-dimensional potential flow analysis iteratively coupled to an integral boundary layer analysis, and a blade element representation of the rotor wake. The code at present runs on a CDC Cyber/855 system.

The mean pressure distribution is measured on the body top surface for various values of separation between the rotor and body. The effects of wake blockage, impingement, contraction, and wake skew are observed. At issue is the ability of the prediction codes to calculate the locations and magnitudes of these features accurately.

Oscilloscope traces of the azimuth-resolved pressure fluctuations at a station on the body surface are recorded, changing as the advance ratio and hence the wake skew angle increases. It is seen that the pressure fluctuations are as large as the mean pressure effects on the airframe, and involve steep gradients in this test case of a highly loaded, untwisted rotor of constant chord. The prediction codes will be used in varying steps of rotor azimuth to compare predictions with measurements.

The changes in velocity components in the wake between the rotor and airframe are observed. Success is demonstrated in performing the measurement using an LDV in a forward flight configuration, and in indicating levels of fluctuations seen in two velocity components within each revolution of the rotor shaft. In the paper, results will be presented on the rotor inflow variations with and without the airframe present, and these will be used to guage the effects of the airframe on the rotor.

The effects of the airframe on the rotor wake will be presented showing the effects on wake skew angle and wake contraction. These will be compared with the predictions of the iterative calculation procedure.

Wind tunnel wall effects are studied using wall pressure surveys and standard interference calculation procedures. Unsteady effects of the wall will be checked using wall measurements.